The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME X

LIBRARY
OHIO STATE UNIVERSITY

OXFORD
AT THE CLARENDON PRESS
LONDON: HUMPHREY MILFORD
1942

254

S3
E55
v.10

EDITORIAL BOARD

SIR E. J. RUSSELL, Rothamsted Experimental Station, Harpenden, Herts. (*Chairman*).
W. V. BLEWETT, Agricultural Research Station, Jealott's Hill, Bracknell, Berks.
J. M. CAIE, Department of Agriculture for Scotland, Edinburgh.
PROF. F. L. ENGLEDOW, School of Agriculture, Cambridge.
SIR A. D. HALL, Long Sutton House, Basingstoke, Hants.
C. BRYNER JONES, Ministry of Agriculture, Welsh Dept., Aberystwyth.
DR. H. A. TEMPANY, The Colonial Office, London.
PROF. J. A. SCOTT WATSON, School of Rural Economy, Oxford.

(*The above constituted the Executive Committee*)

DR. E. S. ARCHIBALD, Central Experimental Farm, Ottawa, Canada.
DR. W. BURNS, Imperial Council for Agricultural Research, New Delhi, India.
DR. C. CROWTHER, Harper-Adams Agricultural College, Newport, Salop.
DR. E. M. CROWTHER, Rothamsted Experimental Station, Harpenden.
DR. I. ELAZARI-VOLCANI, Agricultural Experiment Station, Rehovot, Palestine.
C. T. FAULKNER, Imperial College of Tropical Agriculture, Trinidad.
DR. J. HAMMOND, School of Agriculture, Cambridge.
PROF. J. A. HANLEY, Armstrong College, Newcastle-upon-Tyne.
A. G. G. HILL, East African Agricultural Research Station, Amani, Tanganyika.
SIR F. W. KEEBLE, Cedron House, Fowey, Cornwall.
DR. B. A. KEEN, Rothamsted Experimental Station, Harpenden.
V. LIVERSAGE, Department of Agriculture, Nairobi, Kenya.
RAO BAHADUR B. VISWA NATH, Imp. Agric. Research Institute, New Delhi, India.
DR. R. NEWTON, University of Alberta, Edmonton, Canada.
SIR J. B. ORR, Rowett Institute, Aberdeen.
Dr. C. S. ORWIN, Agricultural Economics Research Institute, Oxford.
H. J. PAGE, c/o The Colonial Office, London.
DR. I. B. POLE EVANS, P.O., Irene, Transvaal, South Africa.
DR. J. A. PRESCOTT, Waite Agricultural Research Institute, Glen Osmond, S. Australia.
DR. A. E. V. RICHARDSON, Commonwealth Council for Scientific and Industrial Research, Melbourne, Australia.
T. RIGG, Cawthron Institute, Nelson, New Zealand.
SIR R. G. STAPLEDON, Grass-land Improvement Station, Dodwell, Stratford-on-Avon, Warwickshire.
SIR F. A. STOCKDALE, The Colonial Office, London.
T. TROUGHT, Gezira Agricultural Research Service, Wad Medani, Sudan.
F. WARE, Imperial Council for Agricultural Research, New Delhi, India.
PROF. R. G. WHITE, University College of North Wales, Bangor.
S. J. WRIGHT, National Institute for Research in Agricultural Engineering.

Secretary and General Editor

DR. E. H. TRIPP, c/o Rothamsted Experimental Station, Harpenden, Herts.

CONTENTS

Number 37

H. A. TEMPANY: Agricultural Marketing in the Colonial Empire 1

CH. COSTER: The Work of the West-Java Research Institute, Buitenzorg, 1938–41 22

A. E. S. MCINTOSH: Recent Developments in Sugar-Cane Breeding in Barbados 31

R. D. REGE: Sugar-Cane Research in the Bombay-Deccan. With Plate 1 43

JAMES STEWART, R. L. MITCHELL, and A. B. STEWART: Pining in Sheep: II. Confirmatory Experiments on its Control by Cobalt-Rich Fertilizers 57

Number 38

T. E. H. O'BRIEN: Rubber Investigation in Ceylon. With Plate 2 61

D. V. WALTERS: Manurial Trials with Irrigated Sultana Vines in the Murray Valley, Australia 77

A. BONDI: The Ensilage of Citrus Fruit Pulp 89

A. BONDI and H. MEYER: The Digestibility of Citrus Feeds 93

A. S. THOMAS: The Production of Jute in Bengal. With Plates 3 and 4 96

DENNIS PAGE: Rabbit-Feeding in War Time 103

W. B. HAINES: A Method for Foliage Comparisons in Field Experiments with *Hevea*. With Plate 5 . . . 117

684765

Number 39

A. J. KERR: A New System of Grass-Fallow Strip-Cropping for the Maintenance of Soil Fertility 125

E. W. GADDUM: Some Observations on Jassid at the Kenya Coast 133

M. H. FRENCH: Development of Live Stock in Tanganyika Territory. V. Skeletal Development of Masai and Grade Black-Headed Persian Sheep 146

GEORGE DUNLOP and ALUN WEST: The Effect of Season on the Fattening of Swine at Various Stages of Growth. 161

E. C. CHILDS: The Mechanics of Mole-Draining . . 169

R. BRAUDE and A. S. FOOT: Cacao By-Products in Pig Feeding: Cocoa-Cake Meal and De-Theobrominized Cocoa-Cake Meal as Feeding-Stuffs for Pigs . . 182

Number 40

H. J. LOWE: Rinderpest in Tanganyika Territory. With Plate 6 189

D. A. E. CABOT: Foot-and-Mouth Disease and its Control in Great Britain 203

A. S. THOMAS: The Wild *Arabica* Coffee on the Boma Plateau, Anglo-Egyptian Sudan 207

F. WIGAN: Improvement in Quality of Australian Butter Exported to the United Kingdom 213

D. C. EDWARDS: Grass-Burning 219

H. P. DONALD and C. AUERBACH: The Duration and Extent of Pedigree Breeding in Herds of Large White Pigs as a Factor in Breed Improvement . . . 232

K. W. NEATBY: New Varieties of Spring Wheat Resistant to Stem Rust in the Canadian West, and their Genetical Background 245

CORRIGENDA

Vol. X, No. 37, p. 52, Table 4, line 4, in lieu of '170 in.' *read* '70 in.'

,, No. 38, p. 70, line 7 and 8 from bottom, in lieu of 'Plates 2 and 3' *read* 'Plate 2'.

,, ,, p. 75, line 8, in lieu of 'unvulcanized' *read* 'and vulcanized'.

,, ,, p. 89, line 3 from bottom, in lieu of 'before ensilage' *read* 'silage'.

,, ,, p. 90, Table 2, col. 5, last line, in lieu of '84·83' *read* '84·43'.

AGRICULTURAL MARKETING IN THE COLONIAL EMPIRE

H. A. TEMPANY

(*Agricultural Adviser to the Secretary of State for the Colonies*)

Introduction

THE prosperity of the agriculturist and his progress in efficiency depend to a large extent upon the marketing of his produce. The outbreak of the war emphasized the importance of marketing problems, particularly in respect of foodstuffs for local consumption, since the stimulus given to increased local production of foodstuffs is unlikely to be fully effective unless adequate arrangements exist for the marketing of the produce. It was felt that it would be useful to ascertain the directions in which further efforts to improve agricultural marketing in the Colonial Dependencies might be desirable, and in 1940 information concerning the marketing conditions for agricultural produce was collected on the initiative of Sir Frank Stockdale, then Agricultural Adviser to the Secretary of State, with the assistance of Directors of Agriculture and Veterinary Services throughout the Colonial Dependencies, from which a detailed survey of the position has been compiled.

The exigencies of the war situation have precluded the publication of the survey until the conclusion of hostilities, but in the meantime it is felt that some account of the more important features of the position would be of interest.

There has been marked progress in the organization of agricultural marketing in the Colonial Dependencies of recent years, and the attention directed to the question in Europe and America has found its counterpart in them. The work of the former Empire Marketing Board and of the Imperial Economic Committee has stimulated development, and inquiries and research initiated by these bodies have been followed by many others of a local or *ad hoc* nature by commissions, committees, and individuals. Efforts have been mainly concentrated upon the marketing of commodities for export, and it is here that the principal developments have occurred; local marketing has been relatively neglected, and there appears to be need for greater attention to this aspect of the question.

The most far-reaching developments are the international regulation schemes for rubber, tea, and sugar, which are designed to stabilize market prices by adjusting production to demand, in each of which the Colonial Dependencies are important participants. At present the Sugar Control Scheme is in abeyance owing to the war; the other two have continued to function. Their success makes it appear not improbable that in due course the principle of controlled production may be extended to other commodities. Apart from their direct action they have had important secondary effects, notably the provision of improved statistical

information regarding the commodities to which they apply, and the better organization of local marketing, particularly in the sugar industry, where control has led in certain colonies to the zoning of supplies of small cultivators' canes to particular factories and the elimination of much unnecessary transport.

War conditions have also perforce brought about great changes in the marketing of many colonial products. The demands of the military situation, food requirements in the United Kingdom and elsewhere, the supply of materials required for the prosecution of the war, and the shipping position have necessitated the intervention of Government on the grand scale, and the control of production, transport, and marketing of the majority of agricultural commodities together with a large measure of price-control. Supplies of sugar, cocoa, rubber, certain oils and oil-seeds, and sisal for example, are completely controlled. For similar reasons it has been necessary to prohibit for the time being the importation into the United Kingdom of a number of commodities, for example, bananas, and in these circumstances special arrangements have been necessary to safeguard these industries; in many other cases also special measures have been necessary to regulate and extend the production of foodstuffs for local consumption: all this has entailed great interference with the normal channels of marketing of agricultural products. This is not the place nor the time for the review of these activities; they are necessarily war-time measures, and a considerable relaxation of them must occur when peace is resumed. It seems, however, not unlikely that experience gained in connexion with them may lead to far-reaching modifications of marketing systems in the post-war period, although at present it is impossible to forecast what direction they will take. In what follows, accordingly, the main features of the marketing position in the different groups of dependencies as it existed prior to the outbreak of hostilities is reviewed, although in places it has been found necessary to include some reference to the effect of war conditions on production and marketing.

West African Dependencies

The Gambia, Gold Coast, Nigeria, and Sierra Leone comprise the West African group of dependencies, and in this group agricultural production is almost exclusively in the hands of native African smallholders. The majority of the holdings are small in size and, with the exception of certain enterprises in mandated territory, there is no development of plantation agriculture. In consequence the marketing of export products has consisted primarily in devising means for the collection of very large numbers of small lots of produce and the combining of these into larger consignments for shipment; trading has been almost entirely organized with this object, and has led to the establishment of trading firms with head-quarters in the ports and coastal towns and systems of middlemen buyers, agents, and representatives throughout the producing areas of the territory, who frequently combine the purchase of native produce with local trade in imported goods.

Export marketing is still for the most part conducted on these lines,

although in the Gold Coast and Nigeria considerable efforts have been made by the governments to establish co-operative societies to enable native Africans to dispose of their produce, notably cocoa. The proportion of the crop disposed of through these organizations is, however, still relatively small. Elaborate proposals for the establishment of a system of group marketing for cocoa in the Gold Coast and Nigeria were formulated by the West African Cocoa Commission in 1937, but so far it has not been found possible to give effect thereto.

Under normal conditions no control is exercised by Government over buying operations; buyers are not licensed and there is no provision for regulating prices. The bulk of the produce is disposed of in the first place to middlemen who resell to exporting firms or their agents. In Nigeria, cotton and ginger can, however, only be sold at recognized market-centres and in the case of ginger the buyers are required to be licensed and their number is limited. Since the outbreak of war certain products, notably cocoa and ground-nuts, are purchased by H.M. Government in the United Kingdom at fixed prices, and in this connexion it has been necessary to introduce as an *ad hoc* measure more extensive control of marketing, including the licensing of shippers and the allotment of export quotas thereto, combined with a measure of control of middlemen buyers.

Internal marketing of produce for consumption in the country is carried out by sales at local market-centres and to itinerant traders. Except in the larger urban centres these markets are not controlled officially, and even in the towns control measures are concerned chiefly with the maintenance of adequate standards in regard to buildings and sanitary conditions and the renting of stalls and stands. In the Gambia there is little exchange of the main food crops and the small village market is almost non-existent, although during the trading season small quantities of the minor food crops are on offer at markets organized under the Markets Ordinance. Fourteen of these are in existence. In Sierra Leone individual producers of rice normally dispose of their surplus to itinerant traders or to shops in villages and towns, but it is interesting to note that in the Scarcies area five small co-operative societies have been formed which, with the aid of the District Agricultural Officer, sell rice generally to the Government rice mill, and thus eliminate the profit that would normally be taken by the middleman. It would appear that given the size of some of the dependencies and the large populations, notably in Nigeria, there exists considerable scope for improvement in the standard of living of the inhabitants through the development of organized marketing of products intended for local consumption. In this connexion provision of credit and a reduction in the cost of transport are in many places factors of importance.

As export trade is concerned with produce of native African agriculturists, the tendency in the absence of control was for much of it to be of a very low standard of quality, and with the growth of competition from better-prepared produce from other countries this was found to be increasingly detrimental to trade. To remedy this, systems of produce inspection have been inaugurated in regard to the more important

articles of export in all dependencies, and have attained a higher degree of development in West Africa than in any other part of the Colonial Empire.

The manner in which inspection is operated varies to some extent in different territories, and in regard to different products, but broadly it consists of compulsory pre-sale inspection at or near the point of origin and the prohibition of sale of produce below a minimum standard, combined with a measure of re-inspection at points of shipment before export. Produce inspection is provided for by ordinances, whilst the manner of its performance is regulated by rules made under the ordinances. A guiding principle which obtains in this legislation is that it is an offence to sell produce which falls below the standards prescribed thereunder. European and African staffs of inspectors are maintained in connexion with the produce inspection services.

The products at present subject to inspection are as follows:

In Nigeria: palm oil, palm kernels, ground-nuts, ginger, cotton, pine-apples, and oranges.
In the Gold Coast: cocoa.
In Sierra Leone: palm oil, palm kernels, piassava, ginger, raffia, and rice.
In the Gambia: ground-nuts.

In certain of the dependencies advisory committees are maintained to advise the governments on questions connected with produce inspection. The effect of inspection has been to raise very appreciably the quality of produce exported. As an example, in palm kernels from Nigeria the mean percentage of impurities has been reduced from 7 per cent. to 4 per cent. and the moisture-content by 2 per cent.

Weights and measures are standardized under weights and measures ordinances, British standard weights and measures being prescribed. Local measures are, however, extensively employed also, especially in buying and selling produce for local consumption. A measure of control and inspection of weights and measures is carried out, usually by the police and sometimes also by agricultural officers, but it would seem that greater control may be called for as cheating by means of inaccurate weighing by small traders is fairly common, especially in rural districts.

In some dependencies—notably Nigeria—there is a considerable export trade in animal products, particularly clarified butter and hides and skins. There is no Government system of inspection in either of these industries. The trade in clarified butter-fat is, however, controlled by the United Africa Company. It is contemplated that in Nigeria closer control over the hides-and-skins trade will in due course be inaugurated.

A number of surveys and investigations of local marketing have been conducted in regard to various industries, the results of many of which have been published. Crop forecasts are issued in respect of the cocoa crop in the Gold Coast and of the cotton and ground-nut crops in Nigeria and prices for produce are published in the local press, but there are no regular market intelligence services. A marketing officer and an

assistant marketing officer have recently been appointed in Nigeria, and the possibility of a similar appointment in the Gold Coast is under consideration.

East Africa

The East African group of dependencies includes Kenya, Northern Rhodesia, Uganda, Nyasaland, Somaliland, Tanganyika, and Zanzibar.

In East Africa export production both by native African agriculturists and by Europeans and Asiatics has expanded rapidly in the past forty years. Intervention by Government has occurred with a view to improving marketing conditions, but more particularly in the endeavour to raise the quality of the produce of African agriculturists.

Export products which have been developed considerably are cotton in Uganda, Tanganyika, Kenya, and Nyasaland, coffee in Kenya, Tanganyika, and Uganda, tobacco in Nyasaland, Uganda, and Northern Rhodesia, maize in Kenya and Northern Rhodesia, sisal in Tanganyika and Kenya, pyrethrum in Kenya and to a small extent Tanganyika, sugar in Uganda, Tanganyika, and Kenya, tea in Nyasaland, Kenya, Uganda, and Tanganyika, wattle bark in Kenya, and hides and skins in almost all territories in the East African region. The production of cloves and copra in Zanzibar is of much longer standing. Cotton and tobacco are mainly grown by Africans on small-holdings, but there is a not unimportant estate production of tobacco in Nyasaland and Northern Rhodesia; coffee, maize, wattle bark, cloves, and coconuts are produced on small-holdings and on estates, whilst sisal, sugar, and pyrethrum are produced almost exclusively on estates.

No general surveys of marketing conditions have been made, but there have been numerous special investigations of various industries.

The main directions in which market organization has so far been achieved are:

(*a*) Establishment of central selling organizations.
(*b*) Establishment of auction floors for export produce.
(*c*) Establishment of native produce markets.
(*d*) Registration of buyers of native produce.
(*e*) Fixation of minimum prices for native produce.
(*f*) Establishment of inspection and grades for produce.
(*g*) Limitation of the numbers of factories for processing produce.
(*h*) Provision of transport facilities.
(*i*) Forecasting of crops and disseminating of information regarding prices.
(*j*) Control and inspection of weights and measures.

The most important central selling organization is the Kenya Farmers' Association, mainly concerned with sales of cereals, pulses, and foodstuffs produced by Europeans. It also acts as agent for the Kenya Pyrethrum Board and handles some native produce, notably coffee. The Maize Control Board in Northern Rhodesia handles the whole of the maize crop in that dependency. The Clove Growers' Association of Zanzibar handles the export of cloves from that dependency, whilst the

Native Tobacco Board in Nyasaland handles tobacco produced on native trust lands.

The Kilimanjaro Native Co-operative Union in Tanganyika is a native African selling organization and handles the coffee crop produced in Moshi. There are also a number of other similar smaller organizations handling produce of African growers, whilst the Kenya Co-operative Creameries handle the bulk of the cheese and butter produced in that colony. Estate produce is, however, mainly sold either direct by the estates or by agents. Since the outbreak of war the selling of sisal has to a certain extent been centralized as the result of the establishment of a Sisal Controller for East Africa.

The auction system of disposal has been mainly developed in the tobacco industries of Nyasaland and Northern Rhodesia, but a part of the coffee crop in Kenya is also sold in this way. In Nyasaland practically all tobacco is ultimately disposed of on the Government auction floor.

Much attention has been paid to marketing native export produce. In earlier days this was for the most part bought by itinerant traders or shopkeepers who resold it; often they paid low prices and resorted to malpractices. They served a useful purpose in the earlier stages of development, but in the interest of the producers are being replaced by sales at officially established markets or buying-posts. Examples are the native administration markets in Kenya and Tanganyika and the cotton markets and buying-posts in Tanganyika, Uganda, and Nyasaland; the coffee markets in Uganda, and tobacco markets in Nyasaland. Buyers at these are licensed and their operations supervised. They are required to exhibit the prices offered for produce outside their place of business, and transactions are for cash.

The system of fixed markets and buying-posts has served to enhance the prices received by growers. The main difficulty is to ensure that they shall be sufficiently numerous and so situated as to be within reasonably easy reach of all growers. The fixation of minimum prices for produce has been undertaken by the governments in respect of certain commodities, notably cotton.

Produce inspection has been introduced into the majority of dependencies and staffs of inspectors are maintained. It most usually takes the form of pre-sale inspection, and is often operated in connexion with native markets. Among articles subject to inspection are cotton, coffee, maize, ground-nuts, cloves, wattle bark, tobacco, and hides and skins. Export inspection is maintained in connexion with maize and wheat from Kenya and maize from Northern Rhodesia. Standard grades have been established for many types of produce, and there is a considerable amount of legislation which regulates the production and marketing of various crops.

Standard weights and measures have been introduced in all dependencies and provision made for inspection of weights and measures, usually through the police forces; the enforcement of the provisions varies; it is usually only possible to enforce the conditions strictly in towns with properly supervised markets, and at established native administration markets and produce markets and buying-posts.

There has been comparatively little organization in the marketing of produce for local consumption, although a survey is in progress with a view to organizing the local sales of produce in the southern highlands of Tanganyika. Native market-centres have for long existed, and in the towns urban markets have been established. Except in urban centres, however, these receive comparatively little supervision. Much perishable produce is retailed by hucksters. In Kenya periodical markets are held in most localities in the native reserves and serve chiefly for the exchange of products such as yams, bananas, and dried fish. Occasionally Indian lorry owners attend these markets and buy produce for outside sale, but these markets still remain partly outside the commercial market systems, serving largely as social occasions; a number of them have, however, become gazetted markets under the Marketing of Native Produce Ordinance (No. 28 of 1935). Similar markets exist in Tanganyika, and here, too, produce is frequently bought and sold for cash and markets are attended by licensed itinerant traders. The majority of the native population of Uganda is self-supporting in food crops and any marketing of these crops is confined to local redistribution. Food crops in Nyasaland are sold at small market-centres which are uncontrolled. Indian traders are found at the larger markets, and slowly stores are being built.

Progress has been made by some Veterinary Departments in the organization of the sales of cattle and the marketing of dairy produce and hides and skins. In Uganda, Tanganyika, and parts of Kenya live-stock markets are held on fixed days under the supervision of the veterinary staff. The system was introduced originally to control disease, but it has been of benefit from an economic point of view and offers advantages in dealing with overstocking. The hides-and-skins trade is controlled to some extent and legislation has been enacted in certain dependencies for controlling the methods of preparation, drying, and grading hides and skins for export. In Northern Rhodesia a cattle marketing board fixes prices for stock on the live-weight basis.

Crop forecasts are issued by the Departments of Agriculture in respect of certain types of produce, and from time to time information is disseminated regarding market prospects.

On the whole it can be said that marked progress has been achieved in the organization of marketing of agricultural produce in East Africa, although further improvement is desirable in certain territories.

Eastern Dependencies

Ceylon, Hong Kong, Malaya, Mauritius, the Seychelles, Aden, British North Borneo, and Sarawak form the eastern group of dependencies.

In Ceylon and Malaya, particularly the former, there is a long-established tradition of settled agriculture, with traditional marketing systems. The development of plantation agriculture in the nineteenth and twentieth centuries greatly expanded export production and led to the extension of the marketing systems along pre-existing lines. In Mauritius and the Seychelles, on the other hand, there is no tradition of a previously existing indigenous agriculture, and developments have followed lines roughly parallel to those in the West Indies.

The main agricultural exports are tea, coconut products, and rubber from Ceylon, rubber, coconut products, palm oil, and canned pine-apples from Malaya, sugar from Mauritius, and coconut products and essential oils from the Seychelles. With the exception of oil palms in Malaya, which are an estate crop only, they are all grown both on estate plantations and small-holdings. From Ceylon and Malaya there is also a considerable export trade in a number of other minor products, including cocoa, areca nuts, gambier, derris, tapioca, and certain spices and essential oils, from Mauritius of Furcroea fibre, and of vanilla from the Seychelles. There have been many inquiries into the economic circumstances of the more important industries in the majority of the dependencies.

There has been marked development of centralized marketing in Mauritius, where the whole sugar crop, now in the region of 300,000 tons, is marketed through the Sugar Syndicate. Mauritius hemp (*Furcroea*) is also marketed centrally through the Hemp Producers' Syndicate, and tobacco through the Government tobacco warehouse. In Malaya, palm oil, which is exclusively produced by estates, is marketed by a combine to which all producers adhere, and which has a working arrangement with a similar consortium in Sumatra, whilst recently a measure of centralized selling has been introduced into the canned-pine-apple industry. In the Seychelles there is a measure of centralized selling in the essential oils industry, otherwise export marketing is on individual lines; large terminal markets for certain classes of produce, notably tea and rubber in Ceylon and rubber in Singapore, have grown up in which produce is bought by local buyers for export on firm orders from abroad. Many of the larger estates and groups of estates themselves export and sell either direct or through agency houses, which also finance, provide supplies for, and supervise the general management of the estates.

In Ceylon and Malaya, small-holders' produce for export, except tea, is usually purchased by produce dealers who are licensed and combine the buying of produce with shopkeeping; they resell their produce to middlemen, who again resell to export dealers in the ports or act as their agents. The system is defective inasmuch as dealers often pay insufficient attention to quality and are unwilling to offer higher prices for produce of good quality, thereby tending to frustrate efforts by Departments of Agriculture to improve the quality. Shopkeepers also advance money and goods against prospective deliveries of produce, and chronic indebtedness is widespread. The produce of tea small-holdings in Ceylon is sold as green leaf to neighbouring estates or to factories.

Current market prices for certain grades of produce are displayed at police stations and Government offices in Malaya, but it is often uncertain what proportion is paid owing to the extreme complexity of the indebtedness position. Some attempts have been made at co-operative trading, but with indifferent success. Otherwise there is no provision for official price-fixation.

In Mauritius, small-holders' canes as well as those of estates without factories are sold to the factories on a basis of the percentage extraction of

sugar. Recently legislation has been enacted which provides for the regional grouping of small growers in regard to particular factories, and prescribes the basis of sale. Tobacco is also purchased at prices fixed by the Tobacco Board. In the Malayan pine-apple industry, fruit is bought on behalf of the factories by itinerant traders. An attempt has lately been made to introduce a uniform scale of prices.

There are Government rice mills in Malaya and Ceylon, and others may be erected in due course. These mills buy paddy at prices fixed by Government and so regulate to some extent the prices paid by privately owned mills.

In Ceylon, legislation was introduced in 1939 to regulate the importation of agricultural commodities and to facilitate the sale of agicultural products (Ordinance No. 29 of 1939). Under the ordinance the importation of those agricultural products which have been specified by order made under the ordinance is prohibited except under licence. An import licence is granted for the importation of a regulated product only after an applicant has purchased and paid for the requisite quantity of the corresponding locally grown product. The ratio for determining the quantity of the local product which an importer must purchase in order to obtain a licence to import a specified quantity of the regulated product, and the price at which a specified grade of this local product will be sold to an applicant for an import licence, are prescribed by the Executive Committee of Agriculture and Lands and notified in the *Gazette*. Legislation is also being considered in Ceylon to provide for the regulation of the sale of agricultural produce through agents, and for the registration and licensing of agricultural produce agents, with the object of protecting the interests of producers. This legislation contemplates the provision of security by agents and the opening by them of trust accounts for customers' money.[1]

Produce for local consumption is sold in markets at urban centres, and in Ceylon and Malaya many village fairs or markets have also been established throughout the country. The degree of control over them varies greatly. Prices for local produce vary widely according to season, and there are often alternating gluts and shortages, especially of fruits and vegetables. The growing of vegetables and fruit by Chinese market-gardeners in Hong Kong and Malaya is, however, well organized. In Hong Kong, stall-holders in urban markets are organized into groups, and to them are attached individuals who finance and assist growers and market their produce through the stall-holders' organization. A similar state of affairs obtains in Malaya.

There is no provision of Government inspection for export produce, except in the Seychelles, where copra and essential oils are subject to inspection before export. A National Mark system of inspection of canned pine-apples for export has, however, been introduced in Malaya, whilst the introduction of a similar system for certain classes of produce is contemplated in Ceylon. Weights and measures are prescribed by law in all dependencies, and inspection duties are carried out by the police.

[1] This has recently been enacted.

There is elaborate provision of statistical services in regard to production of the more important staples in Malaya and also in Ceylon; there is also satisfactory provision for the dissemination of information concerning market prices through the daily press, Chamber of Commerce, and merchants' circulars, and by broadcast information. In Mauritius, statistical services in regard to the production of sugar are maintained by the Department of Agriculture, which issues crop forecasts, whilst market information is disseminated through the press.

There is a Government Marketing Department in Ceylon which is mainly concerned with efforts to increase the demand for Ceylon products, to increase the supply of these products to meet the increased demand, and to organize their orderly marketing. There is no such provision as yet in any of the other colonies. Little or no organization of the marketing of live-stock products has been attempted. Milk is sold by the small producers direct to consumers, and cattle for slaughter to itinerant traders or direct to butchers. In Johore, which geographically is in a favourable position to supply the Singapore market, a pig-marketing scheme is being considered. The essential part of the scheme is that it should be made obligatory for a proportion of all pigs slaughtered in Singapore to be of Malayan origin.

The West Indies

The dependencies comprising the West Indian (and American) group are the Bahamas, Barbados, Bermuda, British Guiana, British Honduras, Jamaica, Leeward Islands Colony (Antigua, Montserrat, St. Kitts-Nevis, and the Virgin Islands), Trinidad and Tobago, and the Windward Islands (Dominica, Grenada, St. Lucia, and St. Vincent).

Agriculture in the West Indies has throughout been based on production for export; there was no pre-existent tradition of indigenous agriculture, and wherever peasant agricultural industries have grown up they have mostly taken their rise as a result of the subdivision of estate properties. Marketing is organized on the basis of export production, and especially of recent years there has been considerable development of marketing organizations. With the exception of Jamaica, however, there has been comparatively little attempt to organize the marketing of produce for local or intercolonial consumption. There have been no general surveys of marketing conditions, but numerous investigations have been made in regard to conditions in various industries.

Sugar is the most important crop; it is grown both on estate plantations and on small-holdings. The proportion of the crop produced on small-holdings varies; it is greatest in Trinidad and Jamaica and least in British Guiana and St. Kitts. The bulk of the sugar crop is manufactured in central factories, which market the produce either direct or through agency houses. A certain amount of grouping of factories has occurred. Many plantations sell their canes to factories on a contract basis, and almost all the peasant-grown canes are sold in this way. In certain colonies peasants are required to deliver their canes to particular factories, the prices paid being controlled on a statutory basis. Special arrangements exist for the marketing of fancy molasses, which is pro-

duced on some scale in Barbados and also in St. Vincent and St. Lucia. Production quotas have been established and an arrangement made whereby all producers of sugar are enabled to benefit from the higher prices at which the product is sold.

In Jamaica the marketing of bananas is now well organized as a result of the recommendations of the Banana Commission of 1936. The disposal of the crop is shared among three companies between which a working arrangement exists, whilst powers are provided for the Government to take over control of the marketing arrangements in certain eventualities. A measure of centralized marketing has been established in regard to the citrus industry in Jamaica, Trinidad, and British Honduras, and in these and certain other colonies packing houses have been established which are either controlled or supervised by Government. In British Guiana, export sales of rice are controlled by Government, whilst as a war-time measure the whole of the arrangements for the purchase and sale of the rice crop both for internal and external consumption have been brought under control. The centralized selling of lime oil from Trinidad, Jamaica, and St. Lucia is also provided through the West India Lime Sales Association, a co-operative organization.

A measure of centralized selling has been introduced for peasant-grown cotton and also exports of fruits and vegetables in certain colonies, whilst co-operative schemes for the purchase of copra and the manufacture of vegetable-oil and lard substitutes therefrom exist in Jamaica, Trinidad, and British Guiana. Owing to low prices and unregulated competition certain of these have experienced difficulties, and in Jamaica the whole of the marketing arrangements for coconut products have been taken over by a Government-sponsored central authority. About two-thirds of the copra produced in Trinidad is marketed through the Coconut Growers' Association Ltd., a co-operative body which has recently invited the growers in all other West Indian Colonies to form a joint selling and manufacturing scheme. The arrowroot crop of St. Vincent is disposed of entirely through the St. Vincent Arrowroot Growers' Association, which has been constituted under legislation enforcing the marketing of the produce in this way; the effects of this has been greatly to improve the quality of the produce and the financial stability of the industry. In Grenada, St. Vincent, St. Lucia, and Dominica bananas for export are also similarly marketed through local producers' associations.

In regard to internal marketing, in Jamaica considerable efforts are now in progress to organize the production and marketing of various grains and other foodstuffs by the Government Marketing Department. In British Honduras a scheme for the purchase and storage of rice, maize, and pulses is operated by the Board ofAgriculture; in certain other colonies, notably Trinidad and British Guiana, depots for the sale of foodstuffs for local consumption have been established with some success.

In Trinidad many estates sell their cocoa to the Cocoa Planters' Association, which handles about 20 per cent. of the island's crop, and a

small amount of cocoa is purchased by Government through two cocoa fermentaries. Four co-operative cocoa fermentaries exist in Tobago for the preparation of cocoa. The produce is disposed of through the Cocoa Planters' Association.

Other export products are for the most part sold individually by estates and small producers. Estates either export direct or sell to local buyers; small-holders sell to produce dealers who are usually licensed and often are also shopkeepers. Frequently they advance money to small-holders, and it is believed that there is considerable indebtedness.

Apart from these efforts there is little organization of internal marketing; local markets are maintained in towns and large villages in which fees are collected from sellers taking stands, and the bulk of the produce for local consumption is disposed of through them and through hucksters. There is room for increased organization in this respect; one need is the provision of storage facilities for produce, the absence of which leads to alternating gluts and shortages with great fluctuations of price. Little has been achieved in regard to the organization of the marketing of the products of animal industry, although recently a condensed-milk factory has been established in Jamaica with the object of providing an avenue of sale for milk.

Standard weights and measures are provided by ordinances, but the degree of control which is exercised over them varies to some extent. Information regarding market prices is disseminated through local publications and circulars and through the press in most of the colonies.

In general one may say that, although the marketing of export produce is on the whole well organized, that of produce for internal consumption and for the intercolonial trade is less so, and there is scope for improvement in this direction.

Mediterranean Dependencies

Agriculture in this group of dependencies, which includes Cyprus, Malta, and Palestine, dates from very ancient times, and agricultural practices and systems of marketing have their roots in the distant past. The marked developments which have occurred since the last war, particularly in Palestine as the result of Jewish immigration, have, however, greatly affected the position, particularly in regard to the citrus industry which has expanded in remarkable fashion.

In Malta and Cyprus and to a considerable extent in Palestine also, cultivation is mainly on small-holdings, the average size of an agricultural holding being 7 acres in Cyprus and 4¼ acres in Malta. In these two dependencies the organization of export marketing is therefore mainly directed towards the collection of the produce of large numbers of small-holders and making it up into commercial-sized parcels for export. Crops grown for export include citrus fruit in Palestine and Cyprus, potatoes, onions and other vegetables, and cumin seed from Cyprus and Malta, and carobs, tobacco, barley, raisins, wine, cotton, and wool from Cyprus. Hides and skins are exported to some extent from all dependencies.

Surveys of marketing of various crops have been made in Malta,

whilst the citrus industry of Palestine has been the subject of numerous surveys and investigations by individuals, committees, and commissions. There has been little intensive investigation of marketing conditions in Cyprus, although the circumstances of certain industries have been the subject of *ad hoc* inquiries. In Malta, marketing conditions have been studied by the marketing branch of the Department of Agriculture.

In Cyprus, sales of export produce are made to middlemen or village traders, who in turn sell to exporters, or may act on their behalf. Their operations are not controlled by law. In Malta, potatoes, cumin seed, and onions for export are sold to brokers who resell to exporters. Brokers and exporters are licensed and their activities defined by law. In Palestine, citrus fruit may be sold to middlemen who resell to exporters, or to the exporters direct, of which the Citrus Co-operatives are the most important and these also export direct on behalf of their members. This provides some measure of centralized selling and under the newly enacted Citrus Control Ordinance powers exist for an increased measure of centralized selling.

Advances are frequently given to growers by middlemen or exporters, and in Cyprus there is a vast network of indebtedness. Here the attempt is being made to develop marketing through village co-operative societies, but this is only in its infancy. In Palestine co-operative marketing has attained a fair degree of extension and numerous co-operative societies exist. In Malta there has been no development of co-operative selling, but the marketing of produce for internal consumption has attained a fair degree of organization; it is handled by a class of people called 'pitkali' who accept delivery on a consignment basis and sell to shopkeepers and hawkers.

Weights and measures are standardized by law, and inspection is provided. Systems of inspection for produce destined for export are practised in all three dependencies. In Palestine it is solely concerned with citrus fruit and is regulated by the Fruit Export Ordinance, under which powers are given to inspectors to examine fruit and prohibit export if it does not conform to standards. The ordinance is administered by the Fruit Inspection Service of the Department of Agriculture. Inspection is performed at the point of shipment, but powers are also provided for control of conditions in the groves, and in packing houses, which also are subject to inspection.

In Cyprus there is no control over quality of goods at first sale, but inspection is provided for the following goods destined for export, viz. aniseed, barley, cumin, linseed, oats, potatoes, vetches, and wheat, under the Adulteration of Produce Law, whilst citrus fruit, potatoes, and onions are inspected at the port of shipment. In Malta, potatoes, onions, and cumin seed are inspected at the port of shipment before export.

In Palestine there is elaborate provision for disseminating information in regard to market prices and market conditions for citrus fruit, the progress of shipments, &c., by means of the press, trade journals, circulars, and broadcast talks. In Cyprus and Malta, although some provision of this description exists, it is much less elaborate. In Malta a special branch of the Department of Agriculture deals with marketing

questions; it handles the export-produce inspection services, and is also endeavouring to improve conditions of internal marketing.

Western Pacific and Atlantic

Fiji, the territories of the Western Pacific High Commission, the Falkland Islands, and St. Helena are the dependencies included in this group.

In Fiji and the Western Pacific Dependencies there was considerable indigenous agriculture prior to the British occupation. In Fiji there has since been marked agricultural development both on estates and small-holdings. The principal crop—sugar-cane—is sold by individual small cultivators to the mills on contract. Copra is sold to local store-keepers and fruit, mainly bananas, for export to licensed buyers; rice is sold to the rice mills. Apart from rice, produce for local consumption is mostly sold direct either to consumers or to roadside markets. There is produce-inspection on first sale for export of bananas, citrus fruit, and cotton. A main difficulty is the lack of suitable transport facilities in the absence of proper roads, and for the development of marketing improved transport facilities are desirable. There is lack of organized village and township markets, but it is hoped that in due course this may be remedied.

From the Falkland Islands the only exports are products of sheep, notably wool, and there is comparatively little production of food for local consumption. The community is a small one. In St. Helena little has been done towards organization of marketing.

General Summary

In the Colonial Empire government intervention for the regulation of marketing has occurred in varying degrees in different dependencies. Where plantation industries are predominant, or where large-scale and small producers exist side by side as in the sugar industry in the West Indies, Mauritius, and Fiji, or the rubber and tea industries of the Far East, intervention has on the whole been less than where production is entirely by small-holders. Estate production automatically involves the evolution of fairly elaborate organizations for marketing, and this tends to provide channels along which the produce of the small-holder can flow.

It is also noteworthy that frequently the marketing of small-holders' produce has achieved greater organization in industries which require elaborate processing of the produce before export, e.g. in the sugar industry or the cotton industry, necessitating the erection of factories. This has simplified marketing, since under such conditions factories tend to buy the raw material from the small producers.

Where, on the other hand, produce is turned out by the small-holder in a form suitable for immediate export, e.g. in the cocoa, rubber, or tobacco industries, the situation is more difficult, and sales tend to remain in the hands of the middlemen buyers. Wherever processing is required the establishment of central depots, where practicable, appears to be to the advantage of the small-holders, for not only does it simplify

marketing, but also leads to the production of a better prepared and more uniform article. There are a number of such depots in many colonies, e.g. for curing tobacco, for fermenting and drying cocoa, and for pulping, fermenting, and drying coffee, but there appears to be scope for a considerably increased provision in this respect in some dependencies.

There has been some development of centralized export marketing, and central selling organizations have been set up in a number of industries, principally in East Africa, the West Indies, and Mauritius; in West Africa and in the Far East developments have been less marked, although in Malaya central selling has been adopted in the palm-oil and pine-apple canning industries. The further extension of centralized selling, leading as it does to the elimination of destructive competition, would probably be advantageous.

One of the difficulties in organizing the marketing of small-holders' produce is that the numerous small parcels that come forward from many centres have led to the existence of large numbers of middlemen buyers. The primary buyers are for the most part small people who often combine produce-buying with retail trade. Often they resell to other middlemen and the produce may possibly reach the exporter after changing hands several times. Each time the produce changes hands a profit or commission accrues and this perforce lessens the returns to the producer.

The primary buyers are often very numerous and operate independently at many points. In the absence of any control of their operations the small producer often fails to obtain a fair price for his produce, and is liable to be cheated in regard to weights. Frequently buyers make advances to small-holders either in cash or in goods against future deliveries of produce, and this has led to widespread indebtedness.

To remedy this various attempts at control have been made. In East Africa and to a less extent in West Africa the plan has been adopted of confining the buying of certain classes of export produce to fixed markets and buying-posts, the disposal of scheduled types of produce at points other than these being an offence. This is combined with the registration and licensing of buyers, the prohibition of transactions other than for spot cash paid at the time of purchase, and the official fixation of minimum prices for produce based upon the current prices in world markets. There are numerous variants of the system, but it has undoubtedly helped to simplify marketing, to ensure fair prices to the growers, and to reduce malpractices. A difficulty is to ensure that market-centres are sufficiently numerous and so located as to be easily accessible to producers. To meet this difficulty in Uganda a system of transporting growers with their cotton to buying centres has grown up.

In the West Indies and Mauritius the transport and sale of sugar-cane grown by peasants is well organized, as is also the marketing of bananas in Jamaica and of Sea Island cotton and fresh vegetables and fruit for export in the Windward Islands and Leeward Islands, and arrowroot in St. Vincent. The marketing of certain other commodities, notably cocoa, is less so, and is mainly through produce-dealers who are usually licensed.

In the Far East purchase of peasants' produce for export by produce-

dealers and disposal through a chain of middlemen is still predominant and but little control is exercised over them beyond licensing. The recent legislation in Ceylon for regulating the sale of produce through agents should be of considerable benefit in protecting the interests of the small producer. It is customary for current market prices to be exhibited in public places such as district offices and police stations, but it is uncertain to what extent sellers obtain these prices, and this uncertainty is enhanced by the widespread prevalence of indebtedness. A further difficulty is that of inducing buyers to pay enhanced prices for produce of better quality than the average, thus tending to discount efforts to improve the quality of small-holders' produce.

Indebtedness is also an extremely important factor; obviously some provision for credit and for making advances to growers to be repaid at the time of harvest are necessary, but in many dependencies the burden of debt weighs heavily on the small-holder and handicaps his efficiency. Interest rates are often exorbitant, and the position of a peasant cultivator who borrows from a trader is particularly unsatisfactory when repayment of the loan is made in produce, as the price given may be substantially below the market value; moreover, the borrower is precluded from selling in the open market and thus gaining any benefit from competitive demand.

The application of co-operative principles is the obvious remedy, and numerous efforts have been made to introduce co-operative marketing, usually in conjunction with the provision of credit facilities. Some progress has been made, notably in the Gold Coast and Nigeria, with the co-operative marketing of cocoa, and in East Africa with coffee, but on the whole the sum total of achievement is still relatively small. Factors hindering the establishment of co-operative enterprises include the difficulty of inculcating among small cultivators an adequate appreciation of co-operative principles and the need for loyalty to the organization, the competition and opposition of existing trade interests, the complication of pre-existing indebtedness and, at times, the difficulty of ensuring adequate supervision.

Official inspection of produce intended for export has been established in many dependencies; it has attained its greatest development in West and East Africa, but has also been established in regard to certain products in the West Indies, the Mediterranean dependencies, and Fiji. There has, hitherto, been little such development in the Far East. Produce inspection has naturally obtained its greatest extension in countries where production lies mainly in the hands of the small agriculturist, since in such conditions, in the absence of any control, standards of quality tend to be very low and, especially when competition from other sources of supply is increasing, this operates adversely against producers and exporters. In West Africa the introduction of produce-inspection has had markedly satisfactory results. It has, however, also been applied with satisfactory results to certain products, notably those of a perishable nature, such as fruits and vegetables, and also to certain other products such as maize, coffee, and cocoa in the case of both large and small producers in certain other dependencies.

Inspection may be either pre-sale or pre-export or both. Pre-sale inspection is mainly confined to the West and East African dependencies and is usually operated in connexion with deliveries by native producers at produce markets and buying-posts or at posts established for the purpose in the producing areas. Pre-export inspection is usually carried out at the port of shipment. Inspection on National Mark lines has lately been introduced into the pine-apple canning industry in Malaya and has been proposed for certain products in Ceylon

The value of inspection may now be said to be very widely appreciated in the Colonial Dependencies, and its extension to territories where it does not at present exist and to cover additional classes of produce may be expected.

Comparatively little has been done towards the organization of the marketing of exports of products of animal industry. There has been some development in the co-operative marketing of butter from Kenya, whilst both in East and West Africa there is an expanding trade in the export of clarified butter-fat and ghee in which a fair degree of organization has been introduced, mainly as a result of the efforts of the Veterinary Departments, in association with private enterprise. There is a large export trade in hides and skins from East and West Africa and small exports from many other colonies. The grading and stamping of hides has been introduced in some colonies, but the trade is largely unorganized, and methods of collection and export are wasteful of effort and not conducive to improvement in quality. There appears to be scope for developments, including the introduction of pre-export inspection and improved methods of purchase and storage.

In contrast to export produce, relatively little has been accomplished towards the organization of the marketing of produce for local consumption. This applies particularly to articles of food and also to some other articles. Much of this is disposed of to travelling hucksters over whose operations little or no control is exercised, or at urban or rural markets. Urban markets are usually provided with more or less adequate buildings and stall accommodation by the Government or the urban authorities, and are supervised to some extent, mainly from the point of view of sanitation and order. Stall rents are charged and weights and measures are inspected and checked. Rural markets are usually carried on by the people themselves, sometimes with assistance and encouragement from the Native Administrations or administrative officers, but frequently no official control is exercised over them. At both kinds of markets goods are sold by hucksters, regular stall-holders and in the smaller markets by the cultivators themselves.

Provision for storing easily perishable foodstuffs is difficult or impossible to arrange, and with some products alternating gluts and shortages with corresponding fluctuations in price are usual. In countries subject to famine the provision of emergency stores of grain foods by the people themselves is a traditional feature which is encouraged by Government, whilst in a few territories there has been some official provision of mills and drying- and storage-plant for cereal grains, such as rice and maize, and for pulses, for local consumption. Similarly, there is but little

organization of the marketing of the products of animal husbandry; milk, other dairy produce, eggs, poultry, and animals for slaughter are mostly disposed of through more or less traditional channels. Here and there some efforts have been made to organize sales, a noteworthy instance being the cattle sales organized by the Veterinary Departments in certain East African Territories.

War conditions have directed attention to the need for increasing local food supplies, and it seems probable that the results of this may persist after the war, in which case the gradual improvement of internal marketing conditions may be expected.

Standard weights and measures are provided by law in all dependencies, and inspection is carried out usually by the police and sometimes by other branches of the public service. The efficiency of the inspection varies rather widely; it is naturally most efficient in urban centres. Provision of statistical data in regard to areas cultivated and production, as well as for the dissemination of information regarding market prices and prospects, varies considerably. In a few dependencies excellent statistical services exist; probably the most efficient are those in Malaya; in others provision is less satisfactory. Reliable statistical data are essential for the organization of marketing and in some dependencies an improvement in this respect is desirable. Provision for the dissemination of market information also varies greatly. In some dependencies it is efficiently done and in practically all some provision for this purpose exists. The development of broadcasting may be expected favourably to influence the position.

Marketing Departments have been established by the Governments in two dependencies, Ceylon and Jamaica, and in a number of others, principally in Africa, marketing officers have been attached to the Departments of Agriculture. In all dependencies officers of the Agricultural—and where they exist the Veterinary and Co-operative—Departments render assistance in connexion with marketing questions, and in the West African dependencies special branches of the departments of agriculture are maintained to deal with produce-inspection.

Discussion

As a general conclusion it can be said that there has been considerable development of organized marketing in the colonial dependencies; this is not to say, however, that the position is uniformly satisfactory or that further developments are not needed. These developments have occurred almost entirely during the period 1920 to the present war.

Prior to 1914 it was universally held that trading should be unhampered by official restrictions, except so far as was necessary to safeguard the public against dishonesty. It was believed that the unrestricted operation of the law of supply and demand might be relied on to provide adequate control of prices and supplies. In such circumstances Government intervention for the improvement of marketing conditions was generally regarded as an unjustifiable interference with the liberty of the subject.

The War of 1914–18 caused great disturbance of normal trading; as in

the present conflict, military necessity demanded a large measure of control over raw materials and food supplies as well as prices. As a contrast with the present conflict, however, control measures were introduced gradually and only as the need for them was demonstrated through force of circumstances. At the conclusion of the conflict the reaction generally was to endeavour to get rid as quickly as possible of restrictions which were held to be contrary to the normal interests of the producer.

As a result, prices for many commodities which were in short supply rose for a short time to almost unheard-of heights, which in turn led to great increases in production and a sudden and catastrophic decline in prices, the effects of which were manifested in the succession of depressions which have been characteristic of the period taken as a whole. To mitigate the effects of this an increasing degree of official intervention in marketing processes has had to be undertaken often at the request of the producers themselves with the objects of: (*a*) safeguarding prices by providing sheltered markets for various classes of products; (*b*) safeguarding prices by controlling production so that it shall not exceed the absorptive capacity of consuming centres; (*c*) safe-guarding the quality of produce to enable it to compete with supplies from competitive sources; (*d*) centralization of selling to eliminate destructive competition between producers in the same area; (*e*) simplification of marketing to eliminate the passage of goods through an excessive number of middlemen all of whom had to draw a profit from the transaction; (*f*) measures to ensure that primary producers, and particularly small producers, shall receive a price for their produce on first sale which bears a fair ratio to the wholesale price on the world's markets; (*g*) generally safe-guarding the interest of the producer, particularly the small producer, by protecting him against exploitation by trading interests, dishonest practices, and the formation of traders' rings and combines to depress the price.

It cannot be said that a general uniform policy has been adopted throughout. Circumstances vary so greatly in the different dependencies in regard to the produce grown, the character of the population, the circumstances of production, and the need for amelioration, that no such generalization in fact is possible. Moreover pre-existing conditions profoundly affect the position. Where marketing arrangements have been long established the introduction of modifications is more difficult if for no other reason than that the maintenance of the *status quo* is a matter of vital importance to existing vested interests, which may be powerful and strongly entrenched.

Variations in the racial characters of the inhabitants are also a factor of importance. In some races commercial instincts are much more strongly developed than in others; the Chinese are perhaps an extreme case; in others they may be notably lacking, as in some, although by no means all, of the African tribes.

The areas which present the most serious difficulties are those in which one part of the population has no commercial instincts and another, native or immigrant, has them acutely developed. Devising measures to meet requirements in these circumstances is a problem of difficulty and

complexity. On the one hand, efficiency demands that goods should be disposed of in the most advantageous manner, but, on the other, equity requires that the proceeds should be distributed in a fair manner between the producer, the recipient, and the various links in the chain between the two. From the point of view of efficiency it is desirable to allow free competition amongst buyers, but in the interests of the producer it is necessary to protect him against exploitation and fraud.

On balance these requirements appear to have been met reasonably adequately, although there is considerable divergence in different parts. The position is far more difficult in areas such as the Far East, the West Indies, and parts of Africa, where trading systems have grown up over long periods of years, particularly as a vast network of indebtedness has arisen which seriously handicaps efforts to organize marketing. In East Africa, owing to the more recent date of developments, the difficulty has not arisen to the same extent, and it has been possible in many areas to prohibit the sale of produce by small-holders to traders except on a cash basis. This has enabled somewhat greater advances to be achieved in the marketing of small-holders' produce than has been possible elsewhere.

It must be admitted that in many cases marketing problems have been tackled in an *ad hoc* manner and with very limited objectives. At times insufficient consideration has been given to the fundamental principles involved and the long range of objectives aimed at. This is hardly surprising, for such problems are often very perplexing and immediate and ultimate objectives may well appear to be incompatible.

Incidentally, it seems not improbable that the best ultimate solution of the problem of the money-lending middleman may be not to attempt to extirpate him entirely, but to educate producers up to a point where he becomes the servant and not the master of the public.

Another aspect of the matter which is brought out is that efforts to organize colonial marketing have been concentrated principally upon the marketing of export commodities, and that hitherto relatively little attention has been devoted to purely internal marketing. This is but natural since marketing of export commodities is relatively a much more compact business to organize, presents less difficult problems, and gives quicker results. Nevertheless, the comparative neglect of internal marketing is unfortunate for the well-being of colonial peoples, and the rise in their standard of living, whether they are regarded as buyers or sellers, is in many areas more dependent on a well-organized internal trade than on the export market.

Generally speaking, fluctuation in the standard of living is greatest in those districts where large areas are covered by a single or a small variety of cash crops grown mainly for export. Greater diversification of agriculture, and particularly the production of a larger amount of food for home consumption, tends to ameliorate the position, since it serves to level out deficiencies resulting from low prices for export staples.

An essential condition for the diversification of agriculture in such areas is the creation of an adequate organization of internal markets for

produce. For all these reasons, therefore, there appears to be ample opening for increasing attention to the marketing of goods intended for local consumption, particularly food products, without relaxing efforts in regard to export commodities.

A final point that emerges is that although great attention has been devoted to activities for the control of marketing, there is still a considerable need for further study of the actual processes of marketing, for it is only in the light of comprehensive studies of the subject that governments can determine with exactitude what their policy should be and to what extent they should intervene in marketing questions. Such investigations might well include further comparative studies of what has been done in different territories.

It is probable that a result of such studies would be to indicate that education in the broadest sense of the word is essential to progress. In many cases, a principal need is the provision of greatly increased staffs of trained native supervisors of markets whose duties it will be to ensure that existing or new markets are properly organized and run. In most cases, however, it is probable that the chief need is a fuller education of the people at large if the full benefits are to be derived from a wider exchange of goods of every kind.

Acknowledgements

In conclusion, it is desired to acknowledge the assistance of the numerous Directors of Agriculture and Directors of Veterinary Services who have supplied the information upon which this summary is based and of the senior officials of the Economic Department of the Colonial Office for criticisms, advice, and suggestions. Acknowledgement is also due to Mr. L. Lord, Secretary of the Colonial Advisory Council of Agriculture and Animal Health, for assistance in preparing the article for the press.

(*Received October 10, 1941*)

THE WORK OF THE WEST-JAVA RESEARCH INSTITUTE, BUITENZORG, 1938–41

CH. COSTER

(*Director*)

THE West-Java Research Institute is a private institution serving all the tea plantations of the Netherlands Indies (138,000 ha.[1]), cinchona cultivations to the extent of over 17,000 ha., and the rubber plantations of the western half of Java and South and West Sumatra (160,000 ha.).

The work of the Institute embraces fundamental botanical and chemical research and plant selection, besides special agricultural, technical, and phytopathological studies of more or less local problems, and advisory work. I shall confine myself here to a consideration of the more general and fundamental researches.

TEA

1. *Botanical investigations.*—Dr. Iz. de Haan has been engaged in a study of the anatomy of the tea plant and published a first paper on the stem and leaf in 1939 [1]. Leaves from plantations at high altitudes are thicker and stronger than those from low-lying plantations.

Transpiration of tea shoots (bud and fourth leaf) was particularly high in the morning [2], although the moisture-content of the leaf remained fairly constant throughout the day. The stomata are open to the greatest extent in the morning hours, but close rapidly with the fall in the rate of transpiration when the leaves are plucked. An average bud-and-fourth-leaf shoot weighing 3·37 grams evaporated 1·5 gm. of water per hour in the morning. The temperature of leaves exposed to the sun was several degrees above the air-temperature, but fell 1 to 2° C. in the shade, owing to evaporation.

Deficiency symptoms in tea have been studied by means of sand and water cultures [3]. Growth is greatly retarded by nitrogen deficiency, the leaves are small and light yellow in colour, and dormant buds predominate so that few new leaves are formed. Sulphate deficiency also causes retardation of growth and yellowing of leaves, but the ratio of dormant to growing buds is normal (1:1). With phosphate deficiency the leaves are dark green to dull blue-green, whilst magnesium deficiency causes a light-yellow coloration of the old leaves except for the parenchyma along the nerves, which remains green. Symptoms of calcium deficiency are most noticeable on half-grown leaves; the colour is normal with light green at the leaf edges, and cessation of growth of the nerves causes the leaves to bend.

A separate study of potash deficiency, which is widely distributed in West Java and West Sumatra, has appeared [4]. The leaves of the lower branches fall off, and the old leaves go dark brown at the edges and die. Deficiency symptoms occur on soils with less than 0·007 per cent. potash soluble in 25 per cent. HCl. The ash of potash-deficient (old)

[1] 1 hectare = 2·47 acres.

leaves usually contains less than 10 per cent. K_2O, as against 20 per cent. in normal leaves. Heavy applications of sulphate of potash eliminate the deficiency symptoms and bring production up to normal.

Vegetative reproduction of tea is of great importance for selection, and methods have been devised with a view to securing rapid multiplication. The usual method of budding requires bud-wood several years old. More rapid methods include whip grafting [5] and propagation by cuttings [6, 7]. In whip grafting, a young, green scion shoot from which a strip of bark 2–3 mm. wide has been removed is placed sideways against a stock stripped of a similar width of bark. After about 10 days the bark of the stock is ringed just above the graft. When the bud has swollen, the stock can be removed above the graft; 80–90 per cent. of such grafts are successful.

Propagation by cuttings can also be very successful if the light, temperature, and moisture relationships are carefully controlled in the seed-boxes, which are cooled with running water. Treatment of cuttings, before setting out, with hortomone-A solution (1:240) has had good results, but heteroauxin, which was quite effective in 1939, was ineffective in 1940, probably owing to deterioration of the product.

Hand-pollination is a most valuable aid in selection work. In the field of floral biology the following observations have been made [8]. The period from flowering to ripening of fruit at Buitenzorg is about 8 months. Twenty-four hours after the bud has opened, the corolla and stamens begin to fall off, and the process is completed in 3 days. The presence of the corollas greatly encourages the visits of insects, and their removal before the flower-buds open practically prevents all pollination. The technique of crossing therefore consists in separating the corollas from the stamens before the buds open, and in pollinating the stigma-lobes with the pollen of the male plant. Closure of the pollinated bud is unnecessary; but this means seed with a germinating power of about 15 per cent. has been obtained.

2. *Selection.*—Purposeful selection of tea in Java dates only from 1915. The early selections of types were done by eye, but a system gradually developed of selection according to productivity based on pluckings from individual bushes. This system has been perfected by Wellensieck [9]. In all, about a million plants were judged by eye, from which about 44,000 were selected by individual pluckings. From these, 2,100 mother trees were finally selected from the majority of which clones were made.

For determining individual production five or six test pluckings, which in this case are made in one year, are sufficient. The requirements which must be satisfied by a mother tree are: a minimum yield of 50 gm. of moist leaf per plucking; production at least three times that of all the original material, and a number of mother trees amounting to not more than 1 per cent. thereof; the desired type and a constant yield.

In this way clones were selected with yields 100 per cent. greater than those obtained from ordinary nursery stock. A large scheme is in operation for the local testing of clones in replicated experimental plots.

A number of artificial crossings between selected clones has recently

been carried out; the seedlings therefrom will also be tested. It has already been clearly shown that the progeny of high-yielding clones produce more than ordinary seedlings.

3. *Chemistry of tea.*—Dr. W. B. Deijs has been studying the chemistry of tea and tea preparation for 5 years.

The young green leaf used in preparing black tea contains in the dry matter 20–33 per cent. of tannins, of which 16–30 per cent. is insoluble in gelatine. The greater part of the tannins can be obtained only in an amorphous state, and consists largely of a gallic ester of catechin. There has also been separated 0·1–0·15 per cent. of crystalline tea-catechin, up to 0·3 per cent. of the gallic ester of tea-catechin, and 0·1–0·4 per cent. of gallo-catechin. The changes undergone by these tannins during the preparation of the tea have a great influence on the quality of the product, particularly on the colour of the infusion.

During withering the green leaf loses 20–30 per cent. of water, and becomes supple and easily rolled. At the same time, starches are hydrolysed, whilst proteins are more or less decomposed and the activity of various oxidizing ferments, of which catalase and peroxidase are the most important, increases. During the first hour of fermentation the activity of the oxidizing ferments greatly decreases as a result of chemical reactions caused by the mixing of the leaf-juices, and the colour of the leaf turns brown. High temperatures also inactivate the ferments. Drying fermented tea *in vacuo* at room-temperature increases the activity of those ferments which effect the oxidation of tannins. Loss of tannins occurs during rolling and the subsequent fermentation and drying; of the tannins remaining in the black tea, 40–50 per cent. are extracted in the infusion.

4. *Preparation of tea.*—The results of several extensive inquiries undertaken by different tea concerns from 1936 to 1941 have been collated and published [10, 11]. Studies have also been made on the deleterious effect of prolonged withering on the quality of tea [12]; on the effect of elevation of plantation and factory on quality [13], showing that preparation in a factory at a high altitude was generally beneficial, whilst the leaf from a highly situated plantation was of appreciably better grade than lowland leaf; and on the grading of rolled leaf and the machinery used for it [14].

5. *Agricultural investigations.*—The first pluckings after pruning, the different plucking methods, and the length of the plucking cycle have been the subjects of many experiments [15, 16]. In a lowland plantation a lengthening of the plucking cycle from 3–4 to 10–11 days increased the amount of commercial leaf in a coarse plucking and reduced it in a fine plucking. The duration of the plucking cycle will thus vary with the nature of the pluck. The quality of the product falls when the plucking cycle is prolonged.

Two papers on planting distances [17, 18] have shown that production from a tea plantation is higher during the first 10 years the closer the planting. Subsequently yields level out, but with heavy fertilizing closely planted gardens maintain their supremacy. Thinning of closely planted gardens according to the productivity of individual bushes is

not generally practicable, and thinning by eye probably has little influence on total production.

A number of fertilizer experiments with sulphur, which greatly increased the acidity of the soil and the availability of soil minerals, showed that sulphur appreciably increased the growth of the bushes and, in many cases, the production over several years [19]. Sulphur applications are particularly successful on young volcanic soils with pH over 5. Liming, on the other hand, is harmful.

A large number of fertilizer experiments has made possible a classification of West-Javan tea soils according to fertilizer requirement [20]. In general, organic nitrogen (oil-cake) is less effective than inorganic. The normal optimal fertilizer application for fully grown tea gardens is 300–500 kg. of sulphate of ammonia and 100 kg. of double superphosphate per hectare per year (2·4–4·0 and 0·8 cwt. per acre, respectively).

6. *Plant-pathological investigations.*—The most serious insect pest of tea in Java is *Helopeltis*, against which a very effective and economic counter-measure has been found in the dusting of gardens with derris powder [21]. Canker of the branches is a common, but not invariable, result of the lesions made by *Helopeltis* in shoots and branches.

On the mycological side much attention has been paid to various root-fungi. The red root-fungus *Ganoderma pseudoferreum* can be effectively controlled by isolating and digging up attacked bushes; the determining factor here is the cost. No satisfactory control has been discovered for the black root-fungus (*Rosellinia arcuata*), which is possibly disseminated by spores as well as by root-contact underground. Another red root-fungus *Poria hypolateritia* and 'bitten-off' disease, caused by a species of *Pythium*, have also been studied [22, 23].

Rubber

Owing to lack of staff, publication of the results of many rubber investigations is much in arrears and references to the literature cannot often be given.

1. *Botanical investigations.*—A series of investigations has been made of deficiency symptoms which are externally similar to those of tea. With phosphate deficiency, the leaves are a darker green, with the older ones tinted brown-red, and stiffer than normal. Incomplete N-P and sulphate nutrition greatly checks growth in both length and thickness.

Hevea seedling plants can be divided [24]. The 'twins' so obtained grow normally and display identical characteristics of growth and production, thus making it possible to carry out strictly comparable experiments. Several such plants were budded with a certain clone, whilst the twin plants were grown as unbudded seedlings. Budded plants on high-yielding root-stocks gave considerably higher production than on low-yielding stocks (arranged according to the productivity of the twin plants).

The mutual influence of stock or scion on the performance of the other has also been shown in other ways, but the relationships between the two are still very complex. There is much diverse evidence that

self-budding has no effect on growth or yield. Attempts to propagate *Hevea* by cuttings have usually failed.

2. *Selection.*—Selection of *Hevea* has doubled and trebled the yields of old estates. In the last 10 years a definite 'ceiling' seems to have been reached. The clone Tjirandji I, which was put on the market in 1928, is still one of the highest yielders.

Nevertheless a great deal of work has been done to improve other qualities, especially resistance to bark diseases, wind damage, &c. The West-Java Station performs 50,000 crossings between the best clones every year, with an average success of about 5 per cent. These seedling families are tested for yield while at the same time they are serving as material for further selection of superior mother trees.

The seedling families of good clones also seem to be good yielders, although they have not reached the level of the highest-yielding clones. They are, however, as susceptible as the older clones to bark diseases and have other undesirable qualities, and require just as much nurturing. There are also possibilities of raising yields by selection of the seed-bed by the 'testatex' or other method of determining the flow of latex, and subsequently in the growing plantation by selective thinning on a yield basis.

Since newly selected material needs local testing of its reaction to local factors, particularly climate, soil type, and altitude, a large and increasing number of local trials have been made. At the end of 1940 the West-Java Station had charge of 32 local trials and 3 experimental rubber plantations of about 300 hectares.

An arrangement was made in 1940 with stations in Ceylon, Malacca, and Sumatra for the exchange of promising new material so that a wider basis of selection could be secured.

3. *Chemistry.*—A great many papers have been published in the *Archief voor de Rubbercultuur* on the chemistry, physics, and technology of rubber latex. Without referring specifically to these, it may be said that the main lines of research have been on the physical and chemical properties of latex and rubber, the bacteriology of the rotting process, possibilities of modifying the rubber molecule, technical applications of rubber, the conservation and creaming of latex, and the effect of different processes on the properties of rubber.

4. *Preparation of rubber.*—In recent years there has been a noticeable development in smoking- and drying-sheds in the direction of 'tunnel' sheds. By improved insulation and air circulation the drying-time could be considerably shortened in many crêpe drying-sheds.

Recent research has shown that wet sheets can be completely smoked in a few hours and can afterwards be rapidly dried. In this way the total time of smoking and drying can be compressed into two days.

Packing rubber in three-ply boxes is costly and unnecessary. Methods have been developed for packing sheet rubber in gunny or in other sheets [25], but it remains to be seen whether these cheap and adequate methods are acceptable to the consumer.

Rubber mould can be prevented by the use of disinfectants, especially paranitrophenol, but a better way is to keep the relative humidity of the atmosphere in the packing-shed below 70 per cent. [26].

The question of coagulator assumes importance in war-time. A bacteriological method of preparing acetic acid from latex serum and spirit has been worked out [27], and has been tested by several concerns. Coagulation with sulphonated oil has also been shown to be feasible, and the method is under investigation [28].

5. *Agricultural investigations.*—One of the most important problems is to raise the productivity of old plantations up to modern standards. Prolonged experiments with the 'two-cut' tap (one made 60–80 cm. above the other) and with the 'high' tap (with a second cut at 2–3 metres height) indicate that yield-increases of 20–40 per cent. can thereby be obtained for several years [29]. Another method of increasing production, at any rate in places where labour is abundant, is to reduce the tappings from, say, 320 to 160 trees, so that tapping can be completed in the early morning. The more careful work that is thus possible also helps to increase yields.

A test of different tapping systems that has gone on continuously for 15 years has given the following results [30]. The yields from the more intensive system (S/2, d/2, 100%)[1] were about 15 per cent. higher than from the lighter systems (S/3, d/2, 67%).[2] Period tapping for 20–30 days gave yield increases of 7 per cent. and 4 per cent. over tappings on alternate days. Brown-bast attacks have been highest with the intensive tapping systems, but it has been found that by halving the length of the cut attacked trees can be maintained in regular production.

A large number of fertilizer trials has shown that on certain soil types a complete NPK fertilizer gives excellent results, on other types only NP is effective, and on yet other (rich) soils no fertilizer response is obtained. On stiff, impermeable soils the construction of blind drains, which are filled with loppings from the vegetation, have appreciably increased yields over considerable periods.

The Research Station has evolved a system of spacing and thinning budded plantations, whereby at first 400–500 trees are maintained per hectare, and a thorough and rapid thinning is made at the end of the fifth year so that by the eighth year the number of trees is reduced to about 270 per hectare. This number is then gradually reduced to 180. Large numbers of stems in the early years give higher yields, but bark renovation is less satisfactory.

Since rubber is planted in the Netherlands Indies up to an altitude of 700 metres, it is interesting to compare its behaviour in the plains and in the elevated plantations [31]. Growth of the same clones under similar soil and climatic conditions was slower at 515 metres than at 250 metres altitude. The criterion of tapability (45 cm. girth at 1½ metres height) was also reached 2 years later, and susceptibility to brown bast was greater, at the higher altitude. Production, however, was about the same.

A comparative test of topping at 3–5 metres height young rubber trees that had not formed side branches showed that topping first increases, but subsequently reduces, density of growth.

[1] i.e. a half-spiral cut tapped every other day.

[2] i.e. a third-spiral cut tapped every other day at 67 per cent. of the intensity of the standard S/2, d/2 system.

6. *Plant-pathological investigations.*—Root-fungi are the chief pests of rubber plantations. The white root-fungus *Fomes lignosus* occurs everywhere in young, and also in older, plantations. In young plantations where the roots of separate trees do not touch, control by removal of affected trees is effective, but in old plantations the root-necks of neighbouring trees must be exposed. Careful removal of root-residues in clearings is necessary, as isolated roots can continue to live in the ground for several years. The fungus spreads more rapidly through clean-weeded ground than under a cover of *Centrosema pubescens*.

The red root-fungus *Ganoderma pseudoferreum* occurs in the heavier soils and attacks older trees. The infection comes mostly from *Albizzia falcata*, which greatly favours the spreading of this fungus. Exposure of the root-necks gives effective control.

Cinchona

The results of cinchona investigations are circulated only to interested parties, and therefore no literature references are given.

1. *Botanical investigations.*—Monthly analyses of bark have shown that the quinine-content undergoes periodical fluctuations during the year. In a 16-years study, an increase in the quinine-content of clones was observed in the early years, but in unmanured plantations a decline set in about the fifth to seventh year and persisted with irregular variations. Manuring, however, maintained the quinine-content or reduced the rate of decline. Different clones behaved differently.

The quinine-content of the bark from the same seedling variety or clone varies according to the soil and environmental conditions. A high content is found where vertical growth is stunted. In these areas *Helopeltis* attacks are common, which further restrict growth and increase the quinine-content.

The quinine-content of the underground bark of the *Succirubra* stock of the graft depends on that of the overground bark. The content of the root-bark is 1·158 times that of the overground bark raised to the power 0·46.

2. *Selection.*—Selection of cinchona was begun shortly after its introduction into Java by selection of mother trees with high quinine-content. The original low content of quinine has been raised to 12–15 per cent., and some clones are known with 17 or 18 per cent. Productive capacity has been doubled or trebled.

The basis of selection is not only the quinine-content of the bark, but also the yield of quinine, which is influenced by the thickness and water-content of the bark and the growth of the tree. Resistance to diseases and pests is also taken into consideration.

Artificial pollination of clones has been very successful. Cinchona is heterostyle, so that only long-styled clones or varieties can be crossed with short-styled. The valuable varieties thus produced give promise of high yields in plantations, besides forming the basis of further selection. A few nurseries have been planted with the desired combination of clones.

3. *Chemistry.*—A method has been devised for determining the

quinine-content of small (2 gm.) samples of bark. The micro-chemical detection of bark alkaloids in living tissue has been studied, but without definite results.

When bark is dried at too high a temperature, a partial decomposition of the alkaloids occurs. A method is being devised for determining the loss by decomposition on drying.

The coarser pieces of bark have been found to contain more quinine than does powdery material; consequently samples for analysis must be very carefully prepared.

4. *Agricultural investigations.*—During recent years a method has been worked out in conjunction with the Forest Experiment Station for estimating the stock of bark and quinine in a plantation. The Forest Station constructed locality, class and yield tables, such as are commonly used in forestry, for various clones and varieties. These were supplemented by tables of quinine-content of bark, according to clone, age, and the manurial condition of the land. This work is not yet completed.

A few tests of spacing and thinning have indicated that closely spaced plantations give the highest yields, but there is a wide range in the optimal density of plants.

Analyses of neighbouring patches of soil of varying productivity showed that the productive soils were characterized almost without exception by a high content of organic matter, high nitrogen, and low carbon-nitrogen ratio. They also usually had more citric-soluble phosphate, more lime, and a higher hydrolytic acidity than the less productive soils.

5. *Plant-pathological investigations.*—Cinchona is susceptible to many diseases. Attacks of *Rhizoctonia solani*, which can be controlled with 'superol', occur in seed-beds, and striped canker caused by a *Phytophtora* is widespread. The black root-fungus *Rosellinia arcuata* is also common. The most serious insect pests are *Helopeltis* and *Pachypeltis*, which can be controlled in young plantations by powdering with derris preparation. There are several harmful caterpillars, but it is found that in serious attacks these are usually parasitized and the attacks come to an end without control measures being taken.

REFERENCES

(*Note.* A.R. = Archiev voor de Rubbercultuur. A.T. = Archiev voor de Theecultuur. B.C. = De Bergcultures.)

1. Iz. de Haan, De anatomische bouw van de theeplant. I. Stengel en blad. A.T. 1939, p. 318.
2. —— De physiologie van waterafgifte van de theeloot. A.T. 1938, p. 71.
3. —— Gebreksverschijnselen bij thee veroorzaakt door een tekort aan de belangrijkste minerale voedingsstoffen met uitzondering van kalium. A.T. 1941, p. 1.
4. —— and A. F. Schoorel, Kaligebrek in de theecultuur. A.T. 1940, p. 43.
5. J. H. van Emden, Eeen nieuwe entmethode voor thee. A.T. 1940, p. 16.
6. —— and Iz. de Haan, Voorloopige mededeeling inzake het stekken van thee. A.T. 1939, p. 75.
7. J. H. van Emden, Mededeeling inzake het stekken van thee. II. A.T. 1941, p. 33.
8. S. J. Wellensiek, Bloembiologie en kruisingstechniek bij thee. A.T. 1938, p. 127.
9. —— Onderzoekingen over quantitatieve theeselectie. IV: Moederboomselectie. A.T. 1938, p. 2.

10. H. A. LENIGER, Enquête rollen en natsortatie 1937 van het Proefstation West-Java. A.T. 1938, p. 226.
11. —— Enquête fermentatie 1938. A.T. 1939, p. 248.
12. —— De invloed van een langdurige verflensing op de kwaliteit van de thee. A.T. 1938, p. 141.
13. —— Bijdrage tot de kennis van den invloed van de hoogteligging van een theeaanplant en de hoogteligging van een theefabriek op de kwalitiet van de thee. A.T. 1939, p. 117.
14. —— Het sorteeren van gerold, nat theeblad. A.T. 1938, p. 253.
15. TH. G. E. HOEDT, P. M. H. H. PRILLWITZ and A. F. SCHOOREL, Bespreking van eenige plukproeven op ondernemingen en in de proeftuinen van het proefstation West-Java. A.T. 1938, p. 148.
16. A. F. SCHOOREL, Plukproblemen in de theecultuur. B.C. 15e. jaarg. p. 2.
17. TH. G. E. HOEDT and A. F. SCHOOREL, Plantverband en uitdunning in de theecultuur. A.T. 1938, p. 310.
18. A. PFÄLTZER, Verdere gegevens van de plantwijdteproef op Pasir Junghuhn. A.T. 1940, p. 118.
19. A. F. SCHOOREL and J. C. VAN SCHOONNEVELDT, Gegevens over enkele zwavel- en kalkbemestingsproeven in den produceerenden theeaanplant. A.T. 1939, p. 145.
20. A. F. SCHOOREL, Resultaten van bemestingsproeven in de theecultuur. Voordracht gehouden op de verg. W.J.L.V. dd. 15 Maart 1941. B.C. 1941, p. 518.
21. IZ. DE HAAN, Helopeltisbestrijding in de theecultuur door middel van derrispreparaten. A.T. 1939, p. 101.
22. A. F. SCHOOREL and K. B. BOEDIJN, De steenroode wortelschimmel (*Poria hypolateritia*). A.T. 1939, p. 19.
23. A. PFÄLTZER, Een voorloopige mededeeling over de z.g. 'Bitten-off disease', een ziekte bij theekweekplanten. B.C. No. 43, 1940, p. 1364.
24. TH. G. E. HOEDT, Heveatweelingen als plantmateriaal voor de praktijk. B.C. 1938, p. 782.
25. H. A. LENIGER, Verpakking van rubber. B.C. 1940, p. 80.
26. —— Het gedurende langen tijd bewaren van rubber. II. B.C. No. 4, 1940, p. 102.
27. L. N. S. HOMANS, Bereiding van verdund azijnzuur uit spiritus. B.C. 1940, p. 676.
28. G. E. VAN GILS, Nieuwe coaguleermiddelen voor latex. B.C. 1941, p. 42.
29. J. C. VAN SCHOONNEVELDT, Tapproeven met twee sneden bij oculaties. A.R. 1941, No. 3.
30. G. AD. HEUBEL, Resultaten verkregen met vijf verschillende tapsystemen. A.R. 1940, p. 571.
31. M. J. DIJKMAN and J. S. VOLLEMA, Resultaten van een hoog gelegen heveacloonentoetstuin. A.R. 1940, p. 557.

(*Received October 11, 1941*)

RECENT DEVELOPMENTS IN SUGAR-CANE BREEDING IN BARBADOS

A. E. S. McINTOSH

(*Geneticist, British West Indies Central Sugar-cane Breeding Station*)

Introduction

THE British West Indies Central Sugar-cane Breeding Station was established in November 1932. The history leading up to its establishment, its organization and financing have been described elsewhere [1]. Here it will suffice to note that the Station's work really entails a development of the cane-breeding carried on for Barbados only by the Department of Agriculture in Barbados since 1887 to embrace breeding for all sugar-cane ecological categories in the British West Indies. This development was made possible through financial contributions by the Colonies served outside Barbados to the funds already provided by the Government of Barbados for its own breeding work. The Station is administered by an advisory committee comprising the heads of the agricultural departments in the contributing Colonies and the Principal of the Imperial College of Tropical Agriculture, with the Director of Agriculture, Barbados, as chairman.

The Colonies served by the Station are Barbados, Trinidad, Jamaica, St. Kitts, Antigua, St. Lucia, Grenada, and St. Vincent, which produce a total annual output of approximately 500,000 tons of sugar.

The Breeding Problems

It was necessary at the outset to survey the sugar-cane growing areas in these islands and note for each the ecological and other conditions affecting seedling-type requirement. This was done and the results have been published in bulletins of the Station [2].

For convenience in the breeding-work, the sugar-cane areas throughout are classified into categories. The basic factors affecting this classification are: (1) soil type including soil-moisture conditions, (2) rainfall and presence or absence of irrigation, and (3) sugar-cane mosaic disease. On these factors a general classification has been made to serve as a working basis, and this classification will be retained unless experience with the seedlings produced suggests any desirable alterations. The categories are:

Category I. Areas possessing soils of at least reasonably good natural or induced fertility, and a good water-supply through direct rainfall or irrigation.

Various pertinent subdivisions of this broad and commonly occurring category are recognized in breeding and seedling allocation. The most important of these are made on a basis of: (*a*) *mosaic disease*, i.e. the degree of its power to affect the varietal situation; (*b*) *the length of the favourable growing-season* as affecting varietal growth-type requirements; (*c*) *ratooning properties*, i.e. areas favouring or otherwise the growth of ratoon crops; and (*d*) *effect on rate of juice-ripening*.

Category II. This category comprises sugar-cane soils which are intrinsically infertile, possessing one or more of the characteristics: poor soil texture, low nutrient status, markedly acid or alkaline reaction, poor drainage with frequent water-logging.

The Breeding Policy

It is obvious that any seedling should possess such general desirable characteristics as ready germination or sprouting with quick tillering and closing in, rapid growth, absence of or scanty arrowing, high yields of easily milled cane of high juice-quality, megasse of high calorific value, clean trashing and heavy fall of trash, quick and strong ratoon growth, and resistance to general pests and diseases, such as mosaic, gumming, red rot and root-diseases, and root- and stem-borer pests.

It is inconceivable that any one seedling, even if it possessed them, could fully express all these desirable properties over the two categories and their subdivisions noted in the previous section. It is therefore essential to particularize in breeding and selecting in order to provide the best for each recognized area.

With so many desiderata for the ideal seedling for each area, it was realized that a wide range in genotypes would be necessary in seedling populations in order to improve the chances of getting the desired types. The breeding policy in general, therefore, has been laid down and evolved to attain this end.

The Breeding Work

(*a*) *Selection of parent material.*—An historical inquiry shows that in Barbados, before the production of new varieties from seed was started in 1888, the commercial varieties then grown were the original varieties Bourbon and White Transparent. These belong to the species *Saccharum officinarum*. They naturally provided the initial parent stock from which seedlings were raised. Over a period of forty years, seedlings were raised and commercially successful ones selected, which in turn served as parents to provide seedlings. Thus the genotypic variability in the species *S. officinarum* was well exploited in Barbados. This period served to evolve from *S. officinarum* a type of seedling well suited to Barbados. Naturally, progress in this direction slowed down and improved seedlings were increasingly difficult to get and the technique for testing to get them required to be more and more precise. It is noteworthy that in the period 1890–1913 ten seedlings of appreciable commercial value were produced, no fewer than seven of which appeared before 1906. From 1914 to 1928 one seedling only of proved commercial value was produced. Since that date up to the present only one outstanding seedling of purely *S. officinarum* parentage has been bred, although three others of lesser prominence have been grown commercially.

In this period of seedling-raising and selection a type was evolved whose natural period of growth was well suited to the growing-season in the West Indies, and it is the possession of this feature which has made Barbados seedlings so successful as commercial canes in the West

Indies. Conversely, there is no doubt that seedlings, highly successful elsewhere, have been failures or comparative failures under West Indian conditions on account of their period of growth being unsuited. The celebrated P.O.J. 2878, bred and selected for the short and intense growing-season in Java, is not suited to the longer season in the West Indies, and is successful only in British Guiana, where the season is short, and in parts of Jamaica, Puerto Rico, and Cuba, where its resistance to mosaic is the deciding factor in its selection.

It was therefore evident that, for breeding, this character of the Barbados seedlings had to be retained, and that research should be directed to such retention conjoined with incorporation from other sources of desirable characters whose counterparts in the Barbados seedlings were weakly expressed. The chief of these may be said to be: (1) slow tillering in the early stages with resulting high weeding-costs; (2) comparatively slow rate of cane-growth; (3) fewness of canes per stool and per acre; (4) tendency to rot during crop; (5) indifferent ratooning power, more especially under unfavourable soil conditions; (6) susceptibility to mosaic and root-diseases; and (7) failure to grow in soils noted above in Category II.

In an initial selection of parent material from species other than *Saccharum officinarum* there were few data for guidance. Interspecific crossing had chiefly been carried out in Java, but it was done primarily to obtain seedlings immune to sereh disease, and, moreover, to provide suitable commercial types for growing conditions entirely different from those in the West Indies. Indeed, it can be fairly stated that, for any one broad set of conditions, no forecasts can be made as to the results of interspecific crossing, and its value can be decided only by trial.

In 1928 it was decided to import and use a fairly representative selection of *Saccharum* material, and to this end, from that year up to 1935, the following material was imported:

Saccharum spontaneum (Indian form): Gehra Bhon, Imp. 618. Dacca. Local Coimbatore.

Saccharum barberi: Chunnee. Hemja. Hathooni.

Saccharum sinense: Uba (Indian form). Uba (Hawaiian form). Merthi. Kavangire. Oshima.

Saccharum officinarum (other than Barbados forms): D. 49/30, D. 66/30, D. 625, D. 1135, Badila, Q. 813, H.Q. 409, G. 119, S.W. 111, E.K. 28.

The above are representatives of species. In addition, the following derivatives of interspecific crosses were also imported:

Saccharum officinarum × *Saccharum spontaneum*:

(*a*) Java form of *S. spontaneum*: Kassoer. Synthetic Kassoer. P.O.J. 2364, 2714, 2722, 2725, 2878. M. 28, M. 42.

(*b*) Celebes form of *S. spontaneum*: Toledo.

Saccharum officinarum × *Saccharum barberi*: P.O.J. 213, 228, 234, 826, 979, 2222, 2379. Co. 213. C.P. 807.

Saccharum officinarum × *S. barberi* × *S. spontaneum*: Co. 281, Co. 290. C.P. 28/11, C.P. 28/19.

The above importations formed with the Barbados seedling-material the parent stock used from 1928 onwards by the methods and with the results to be outlined later.

As a result of the writer's visit to the International Society of Sugar-cane Technologists' Conference in Louisiana, in 1938, arrangements were made with Dr. E. W. Brandes, Chief of the Division of Sugar Plant Investigations of the U.S. Department of Agriculture, to import new wild types discovered in expeditions to tropical and sub-tropical countries in the Eastern Hemisphere. These were received in Barbados during 1940 and 1941. They include types and interspecific derivatives of the new species *Saccharum robustum*, and several new forms of *S. spontaneum*. These are considered to be improvements on the earlier introductions for purposes of breeding for West Indian conditions because they have a growing-period more in keeping with the length of the West Indian growing-season. They are:

Saccharum spontaneum: Burma Imp. 848. Pasoerean Imp. 555. Tabongo Imp. 578. Kloet Imp. 564.

Saccharum robustum: 28 N.G. 105 Imp. 654. 28 N.G. 251 Imp. 496.

Erianthus arundinaceus: 28 N.G. 7 Imp. 631.

Saccharum officinarum × *S. robustum*. C.P. 32/156. 32 M.Q. 579 Imp. 868. 32 M.Q. 135 Imp. 866. 32 M.Q. 629 Imp. 869. 32 M.Q. 657 Imp. 870.

In addition, two Coimbatore varieties which have performed well recently in Trinidad have been imported as parents. These are:

Saccharum officinarum × *S. barberi* × *S. spontaneum*: Co. 419.

Saccharum officinarum × *S. spontaneum*: Co. 421.

These recent importations have not yet been used for breeding, so that attention will be confined to the breeding with Barbados seedlings and the varieties imported between 1928 and 1935.

(*b*) *Breeding technique.*—The technique employed has been detailed elsewhere [3]. Briefly, crossing only is carried out, except where it is desirable to be certain of the male sterility of a parent, when selfing is done. The desired crosses are assured by using only male-sterile varieties as mother plants, and by the use of cane-arrow lanterns to enclose the arrows of those and so exclude foreign pollen. During the breeding-season, arrows of the desired male parents are collected around 5 a.m. to 6.30 a.m. daily, i.e. prior to full dehiscence and pollen shed, the arrows of each male parent being kept distinct by enclosing in paper folders [4]. From 7 a.m. to 9 a.m., depending on humidity conditions as they affect shedding periodicity, the arrows of the mother plants in the lanterns are dusted (pollinated) with their respective intended male arrows. The arrows in any lantern are dusted daily until all flowers in all the arrows enclosed have opened. The arrows in the lantern are then allowed to ripen their seeds under the protection of the arrow lantern and in due course are collected, labelled, and taken to the Experiment Station. Here they are sun-dried for three days and their fuzz sown in boxes. From the boxes the seedlings are pricked out into 6-inch clay pots and allowed to grow in these until about 18 in. high, when they are transferred to the field nursery.

(*c*) *Selection of crosses to be made.*—In an article by the writer [5] the policy adopted in the initial selection of crosses to be made between purely noble-cane[1] Barbados varieties was described. Briefly, it consists in the elementary principle of avoiding inbreeding as far as is practicable. This principle was also observed in back-crossing in the course of nobilization work.

In the wider field of crossing, i.e. crossing between species, it was at first the invariable policy to use as one of the parents a Barbados seedling of proved commercial value. It was natural to regard these Barbados seedlings as possessing the fundamental pattern of characters suited to West Indian conditions, and to attempt to overcome the weaknesses in this pattern by introducing characters of other species, where these were strong. In such highly heterozygous material as sugar-cane, however, the only proof of the value of a cross lies in the calibre of the progeny it produces. Thus was evolved an elaborate system of progeny testing, the chief aim of which was to decide in general the most fruitful interspecific crosses, and in particular to find out the actual crosses which produced the higher ratios of desirable commercial seedlings. The latter, in subsequent breeding-work, were more thoroughly exploited whilst weak parent-combinations were discarded.

The system, therefore, in brief can be stated as one designed in the first place to increase the range of phenotypic expression in the seedling progenies, and to serve to concentrate on producing seedlings from the more successful combinations. In any one year there are made, therefore, what might for convenience be termed experimental crosses and proven crosses: the former being combinations tested for the first time, the latter being combinations whose progenies have already been shown to comprise many desirable seedlings.

There is nothing new in the method, but for success, great accuracy is required in the actual crossing and the seedling-testing work.

In the earlier stages of the new breeding-work emphasis was laid on progenies from purely noble-cane crosses, since these contained types of immediate suitability to West Indian conditions. But, as the process of crossing Barbados canes to canes of other species continued, and the best of the resulting progeny were back-crossed to Barbados canes, a type of seedling suited to West Indian conditions and possessing greater virtues than the purely Barbados noble canes has been evolved. In fact the nobilization work on the species and their derivatives noted earlier has reached the stage of producing excellent commercial types: so much so that crossing between purely noble canes has been discontinued.

The policy now is to combine with each other good nobilized seedlings of different lines of interspecific derivation, and thus attempt to combine the virtues of all species employed.

[1] Varieties of sugar-cane which are derived from the species *Saccharum officinarum* only are conveniently termed 'noble' canes. The process of crossing varieties of *S. officinarum* with those of any other *Saccharum* species is called nobilization. A first cross between a variety of *S. officinarum* and a variety of another *Saccharum* species is termed 'first nobilization'. A back-cross of such a 'first nobilized' seedling to a noble-cane variety is termed 'second nobilization', and so on.

Testing, Selection, and Dispatch of Seedlings

Seedling-testing is designed to serve two purposes, i.e. (1) to test crosses and (2) to provide potential commercial types. With this two-fold object in view, the seedling progenies from the crosses are segregated into the progenies of (1) experimental crosses, and (2) proven crosses. Progenies of the latter are grown in blocks, and are used solely for the selection of potential commercial seedlings. Progenies of the former are now grown in randomized blocks, the plot of the progeny of any one cross in any one block being placed at random in that block, and in number being equal to that fraction of the total number of the progeny planted as there are replicated blocks. Thus, a progeny of, say 120 in a layout of 6 randomized blocks would contain 20 seedlings as its representative in each block. This 20 is regarded as a unit. Previously, such a progeny of 200 seedlings would have had each of its members placed entirely at random in a block comprising all seedlings of all experimental crosses. This procedure, although statistically very accurate, was very laborious, and, moreover, precluded the possibility of seeing the progeny of any cross in a group: a very desirable feature in that it allows the selector to get an impression of the type of seedling produced by the cross.

Previously, the first season of test used to last in the field from April of one year, i.e. when the pot seedlings were about 18 in. high and ready for planting in the field, until the next March, when they were cut, data taken, and first season's selections made. Experience showed that in the West Indies—where the growing-season is as a rule 15–18 months—this testing over a period of 11 months was an extremely dangerous procedure. In this comparatively short season, short-season types of seedlings showed up relatively well and bulked largely in the selections. When grown subsequently over the normal longer season they were found to be quite unsuited to taking full advantage of the longer season. This was especially so with some of the early nobilizations, and led to considerable disappointment in this aspect of the work.

The scheme of first-season testing was therefore altered. Now, the seedling progenies from the pot-stage are close planted in April in a field nursery and approximately 80 per cent. replanted by cuttings from this nursery in the following October–November: a minor elimination of 20 per cent. being effected on obvious features such as bad trashing, arrowing, too few canes, &c. This trial lasts from October–November throughout the next year until the crop-period of the following year, i.e. for a normal growing-period. The effect of this change on the value of seedling selections has been striking and its advantage cannot be too strongly stressed.

Although the numbers vary from year to year, on the average it may be stated that annually 70 crosses are made during October–December, of which 60 are experimental and 10 proven. Germinations exceed 100,000 seedlings, of which 22,000 are potted during January–February, 12,000 seedlings are planted in the nursery during April, and 10,000 in the first-year trial proper during October–November.

At the reaping of the first-year trial, seedlings of the proven crosses are cut and laid down alongside field scales. Field selections are made on general appearance, weight, and brix values of the juice. Field selections are then taken to the yard of the Experiment Station, where final selections are made. In the field, selections average about 10 per cent. of the seedlings cut. Final selections are around 2 per cent. of the seedlings cut.

Seedlings of the experimental crosses are cut and for every one the following data ascertained: (1) number of canes, (2) number of rotten canes, (3) length and width of an average cane, (4) percentage of canes arrowing, (5) weight, and (6) juice brix value. Subsequently, average values and degree of variability in each of these characters are determined for the progenies of each experimental cross, and comparison is then made with figures for similar characters in a progeny of a standard proven cross, which is included in the experimental cross group to serve as a basis for comparison.

In addition, selections of potential commercial canes are also made, and this gives for the progeny of each experimental cross percentage field and final selection figures. With these data, and those detailed above, the value of the cross is determined and its future fate settled, i.e. it is either discarded from subsequent use, or it is promoted to the proven cross group.

The selected seedlings are then multiplied and subjected to a series of field trials culminating in variety trials for the survivors. These trials are so situated as to cover the ecological areas in Barbados, and are carried out on systems of modern experimental technique. They have already been described in detail [6].

At an early stage in this sequence the reaction of the seedlings to mosaic disease and gumming disease is determined [7]. Seedlings susceptible to gumming disease are eliminated. The mosaic-disease tests are done principally on behalf of Jamaica, but the value of these tests for Jamaica is strictly limited on account of the probable existence of different strains of the mosaic virus in the two islands. This phenomenon is now being investigated.

Dispatch of seedlings.—At the conclusion of the second season of test in Barbados all final selections are sent to the Plant Quarantine Station in Trinidad, whence, after quarantine, they are sent to the several contributing Colonies accompanied by notes on each and suggestions for preliminary observations and subsequent trials. Schemes for preliminary observation and subsequent field-testing are essentially similar in all the islands. The Station is informed at intervals as to the progress of the seedlings in the various tests, and recommendations for further testing are issued by the Station at appropriate intervals. Periodic visits to the contributing Colonies are made by the geneticist of the Station. The information thus accumulated serves to guide the breeding and selection work.

A Brief Review of the Results

It was pointed out above that the earlier breeding-work done by the Station tended to stress breeding with purely noble-cane stock. As test-

ing technique improved, and the potential value of interspecific crossing became apparent, the policy gradually shifted from purely noble-cane breeding until eventually nobilization and crossing between derivatives of different lines of interspecific crosses were exclusively carried out. It will be evident from what follows that this policy is justified.

In a brief review of the results so far achieved, therefore, the results of purely noble-cane breeding will be first considered, followed by the results now emerging from the nobilization work.

(*a*) *Noble-cane breeding.*—The Barbados varieties used as parents comprised the existing standard commercial varieties, the older varieties of repute, and newer seedlings which had succeeded in reaching the penultimate stage in the sequence of field trials. Of all of these, those most frequently used were: S.C. 12/4, B. 391, B. 417, B. 603, B. 606, Ba. 6032, B. 6450, B. 6835, Ba. 8069, Ba. 11569, B.H. 10 (12), B. 2935, B. 3013, and B. 3439. Of this lot, only Ba. 11569, B. 3013, and B. 3439 proved male-sterile and were used as mother plants for crossing. The imported noble-cane varieties used were: from Demerara, D. 625, D. 1135, D. 49/30, D. 66/30; from Guadeloupe, G. 119; from Java, S.W. 111, E.K. 28; and from Queensland, Badila, Q. 813, H.Q. 409. These all proved to be male-fertile and could serve only as male parents.

From 1928 to about 1933, Ba. 11569 was the mother parent used; in the years following, B. 3013 increasingly replaced it, and it, in its turn, was largely replaced from 1937 onwards by B. 3439, a variety which has proved to be an extremely valuable parent plant.

By the system of progeny-testing noted earlier the best parent combinations were found to be:

Ba. 11569 × B.H. 10 (12)
" × Ba. 6032
" × B. 603
" × B. 417
" × Q. 813
B. 3439 × B.H. 10 (12)

B. 3013 did not function as a good parent when crossed with noble canes, although it has proved an excellent parent in nobilization work. The varieties S.C. 12/4, B. 6835, the Demerara seedlings, and S.W. 111, all tended to produce short-season types of cane which are unsuited to West Indian conditions. Seedlings of S.W. 111 tended to have very thin canes, seedlings from Badila were very susceptible to drought in the early stages, and seedlings from G. 119 were very susceptible to rotting during crop.

From 1928 to 1937 approximately 40,000 seedlings of purely noble-cane origin were reaped as first-year seedlings. Of this number only four have reached the commercial stage, i.e. B. 2935, B. 3013, B. 3127, B. 3439—a ratio of 1 for every 10,000 seedlings grown. The parentages of these are as follows:

B. 2935 = Ba. 11569 × Ba. 6032
B. 3013 = Ba. 11569 × (male parent unknown)
B. 3127 = Ba. 11569 × B.H. 10 (12)
B. 3439 = Ba. 11569 × Q. 813

The seedlings B. 3013 and B. 3127 occupy about 10 per cent. of the acreage in Barbados but do not appear to be suited to the other Colonies. B. 2935 is essentially a variety for areas with good soil and low rainfall. It is at present the predominant variety in Barbados (46 per cent.) and in St. Kitts (50 per cent.). In Antigua it is now largely grown in the lower rainfall areas in soils conducive to ratooning. In Jamaica it fails on account of high susceptibility to mosaic disease, and in Trinidad it suffers from too much soil moisture.

The seedling B. 3439 has a limited value in Barbados, but it is proving exceptionally well suited to parts of Trinidad and a large part of Jamaica where, for a noble cane, it is showing a remarkably high degree of resistance to mosaic disease. In Antigua and St. Kitts it promises to occupy considerable fractions of the sugar-cane acreages. In all of these islands it is only now being extended commercially, but it is possible that it may be grown on a large commercial scale in each of them. It is undoubtedly the best general purpose noble-cane seedling produced by the Station.

It is clear, however, that even with the improvements in breeding and testing methods, purely noble-cane breeding for West Indian conditions has now shot its bolt. It can no longer provide seedlings which show a spectacular improvement on existing commercial standard varieties. In short, it would seem that the potential genotypic variability has been rather fully expressed in the progenies tested and, in these, selections have been made of the best which the testing system is capable of allowing. This work was therefore stopped in 1939.

(*b*) *Nobilization and crossing between derivatives of interspecific crosses.*—The noble-cane material used as a basis for the nobilization work comprises essentially the Barbados varieties listed in the above section.

The wild-cane material used is listed in the earlier section on selection of parent material. With the exception of the recent (1940–1) importations all listed have been tried as parents. Of these, for one or more of the reasons—absence of arrows, interspecific sterility or very low fertility, progeny of poor appearance—the following were discarded: Gehra Bhon, Dacca, Chunnee, Hemja, Hathooni, Uba (Indian form), Merthi, Kavangire, Oshima, P.O.J. 228, 826, 979, 2222, 2714, 2722, C.P. 807, C.P. 28/11, C.P. 28/19. The varieties left, therefore, as parents which have proved fertile and given, on crossing, progenies of greater or less promise are:

Saccharum spontaneum (Indian form): Local Coimbatore.

Saccharum sinese: Uba (Hawaiian form).

Saccharum officinarum × *Saccharum spontaneum*: (*a*) Java form: Kassoer. Synthetic Kassoer. P.O.J. 2364, 2725, 2878. M. 28, M. 42. (*b*) Celebes form: Toledo.

Saccharum officinarum × *Saccharum barberi*: P.O.J. 213, 234, 2379. Co. 213.

Saccharum officinarum × *Saccharum barberi* × *Saccharum spontaneum*: Co. 281, Co. 290.

Short notes on the progress made with these derivatives are appended.

Saccharum spontaneum (Indian form). The variety used—Local

Coimbatore—is grass-like in appearance. It is extremely vigorous and, so far, has proved resistant to mosaic and gumming diseases. It was originally crossed with Ba. 11569 and derivatives back-crossed to the noble canes, B. 3013 and B. 3439. First- and second-degree nobilized seedlings have recently been crossed with nobilized derivatives of the Java *Saccharum spontaneum*, the so-called 'Glagah'. So far, no potential commercial seedlings have emerged, but the appearance of the later nobilizations is sufficiently promising to justify a continuation of this work.

Saccharum sinense. Varieties of this species have proved rather infertile when crossed with other species. The Hawaiian form has, however, given a few seedlings and these have been preserved for further nobilization work. It was first crossed in 1933 with B.H. 10 (12) and P.O.J. 2878. In 1938 derivatives were crossed with noble canes and with nobilized derivatives of the glagah line and the chunnee (*Saccharum barberi*) line. In 1939 uba-nobilized derivatives were again crossed with representatives of the glagah line and with others of mixed derivation (i.e. derived from more than two *Saccharum* species). This was repeated in 1940, when upwards of 500 seedlings were obtained and over 400 planted in the nursery. In addition, uba-nobilized derivatives were crossed with seedlings derived by nobilization of the Celebes *Saccharum spontaneum* and with seedlings of mixed derivation. No commercial seedlings have yet emerged, but this line of work is to be continued.

Saccharum officinarum × *Saccharum spontaneum* (Java form). Seedlings of this derivation have been extensively crossed with Barbados seedlings and derivatives of these crosses crossed back to Barbados seedlings and also to seedlings derived from nobilization of other species and seedlings of mixed derivation. The chief aim here is to produce a seedling suited to the good growing conditions in Jamaica and at the same time resistant to mosaic disease. In this section the most promising seedling so far produced is B. 35187, which was derived as follows:

P.O.J. 2725 × B.H. 10 (12)
B. 3172 × B. 391
B. 35187

In Barbados this seedling is highly resistant to mosaic disease, and is already proving superior in commercial plantings to the standard high-rainfall-district variety B.H. 10 (12). It has not yet been tested in the contributing Colonies. Several other promising commercial types have been produced in this section, but so far they are insufficiently tested to give definite proof of their commercial value.

The nobilization of Java glagah in Barbados has reached the fifth degree. It is not intended to carry this any farther, since the virtues—more particularly resistance to mosaic—of the glagah progenitor may become lost. Derivatives of this nobilization are, however, now being extensively crossed with derivatives of nobilizations of other species.

Saccharum officinarum and *Saccharum spontaneum* (Celebes form). The form of the latter used—Toledo—is said to be a naturally occurring first cross between a noble cane and the Celebes *spontaneum*, the so-called 'tabongo'. The variety toledo is a heavy stooling, heavy-arrowing thin cane of great vigour. The tabongo of Celebes has through its first nobilized variety, toledo, been nobilized in Barbados to the third degree, and representatives of its second and third nobilization crossed with derivatives of glagah, uba, and chunnee nobilizations and nobilizations of mixed derivation. Seedlings of the second degree of nobilization in this section show appreciable commercial promise, more especially for the poorer soil areas of Category II. These are B. 35197, B. 35200, B. 35204, B. 35247, and B. 37227. They are now being tested in large-scale field trials in Trinidad and Antigua.

Saccharum officinarum and *S. barberi*. Nobilization of the original material in this group has produced some very promising seedlings. The Java variety P.O.J. 234 crossed with Ba. 11569 has given rise to a seedling, B. 35245, a thick-cane type of high juice-quality and exceptional ratooning power. It is, however, susceptible to mosaic, which will eliminate it from Jamaica, but it is expected to become a commercial variety in all the other contributing Colonies. The variety P.O.J. 2379 when crossed with B.H. 10 (12) gave rise to one of the best female parents now in the Station—B. 3365. This variety when crossed with B. 603 has given rise to B. 37161 and B. 37193. The former is a seedling of outstanding merit. So far, it has been in tests in Barbados only where, in comprehensive trials reaped in 1941, it outyielded the standards under all ecological conditions by 20 to 70 per cent. Such superiority in final trials has never been previously encountered. The cane-tonnages and juice-purities are high. It is expected that eventually it will occupy at least 60 per cent. of the acreage in Barbados. So far, it has not yet reached testing stage in the other Colonies, which lag behind Barbados on account of the necessary quarantine period at the Plant Quarantine Station in Trinidad prior to their liberation for test. It is certain, however, that it will become a commercial variety in all contributing Colonies.

Co. 213 when crossed with Barbados noble canes proves to be rather infertile, whilst with P.O.J. 2878 it has been rather less so. Promising seedlings of the former are B. 35207, B. 35214, and of the latter B. 37174, B. 37175, and B. 37176.

Saccharum officinarum × *S. barberi* × *S. spontaneum*. The two varieties used here, Co. 281 and Co. 290, particularly the latter, have proved to be excellent parent plants. They are therefore being freely used for breeding. At present the cross B. 3439 × Co. 290 is the best on the Station and is giving in its progenies remarkably high field and final selection figures. The cross Co. 281 × B.H. 10 (12) has produced the seedling B. 34104, a medium-width cane; it is a heavy stooling, exceptionally vigorous, high-sucrose seedling of a wide range in adaptability. In Trinidad in early trials it was so outstanding that planters rapidly increased its commercial acreage even before its value was conclusively proved. Its susceptibility to mosaic will debar it from any large-scale

planting in Jamaica, but in all other Colonies it is certain to become a commercial variety.

The nobilization work has therefore produced within a few years from its commencement such outstanding varieties as B. 34104, B. 35187, B. 35245, B. 37161, and B. 37193. Over all, these varieties, in addition to showing greatly superior yields to the standards, are suited to a wider range of conditions. Thus, B. 34104, B. 37193, and B. 37161 may be expected to replace the large acreages of uba and Co. 213 that are grown in poorer soils in Trinidad, Antigua, and Jamaica, in addition to replacing noble-cane standards in good soil areas. B. 35187, it is hoped, will show commercial resistance to mosaic in Jamaica and thus displace P.O.J. 2878 in good soil areas where it (P.O.J. 2878) is grown in place of B.H. 10 (12) because it is resistant to mosaic.

Further, these five seedlings, besides showing much greater superiority over the standards than the four noble-cane seedlings noted earlier as produced by the Station, were selected from approximately 9,000 first-year nobilized seedlings, a ratio of 1 : 1,800, as compared with the ratio for noble-cane seedlings of 1 : 10,000. The value of the nobilization work is therefore conclusive and these facts justify a stoppage of purely noble-cane breeding.

Future Policy

The nobilization work so far done is tending to indicate suitable parents and combinations of parents for the production of seedlings suited to the wide range of conditions served by the Station. Whereas at first the tendency was to nobilize within the species, recent policy has been to cross between derivatives of nobilizations of different species with the elementary conception of trying to combine in individual seedlings in the progenies the virtues of all the species. In breeding, the selection of parents is being initially made by selecting the best seedlings for this purpose and confirming or otherwise the wisdom of this selection by progeny testing.

The material started with in the period 1928 to 1935 will last for many years yet before its potentialities are exhausted, but, in the meantime, it is the intention to start early nobilization work on the new parent material imported in 1940–1.

REFERENCES

1. A. E. S. McINTOSH, Trop. Agric. 1936, **13**, 204–12.
2. —— B.W.I. Cent. Sugar-cane Breeding Stat., Bulls. Nos. 1, 2, 3, 4, 7, 13, 15, 19, 22.
3. —— ibid., 1935, Bull. No. 6.
4. —— Trop. Agric., 1930, **7**, 296–9.
5. —— Agric. J., Dept. Sci. & Agric., Barbados, 1932, **1**, 3–17.
6. —— and C. B. FOSTER, B.W.I. Cent. Sugar-cane Breeding Stat., 1935, Bull. No. 9.
7. —— and G. C. STEVENSON, ibid. 1935, Bull. No. 8.

(*Received October 10, 1941*)

SUGAR-CANE RESEARCH IN THE BOMBAY-DECCAN

R. D. REGE

(*Crop Physiologist and Principal Agricultural Officer, Sugar-cane Research Scheme, Padegaon, Bombay Province, India*)

WITH PLATE I

THE Bombay-Deccan consists of a belt of country some 120 miles wide along the eastern side of the Western Ghats and lies wholly in the south-west portion of the geological formation known as the Deccan Trap, from which all the Deccan soils have been derived. This belt can be divided into three zones, depending upon the nature of rainfall, viz. (1) hilly, heavy monsoon-tract, (2) transition tract, (3) flat tract of precarious rainfall. Although the transition tract suffers from frequent scarcity of rainfall, it is as a rule rarely liable to famine. The tract of precarious rainfall comprises the smaller or larger parts of the districts of Ahmednagar, Poona, Satara, and Sholapur, which lie between the parallels of north latitude 16° and 21° of the great plateau of the peninsular India. The total rainfall varies between 18 and 25 in., with extremely precarious distribution, and years of good distribution are rare. Before the advent of the canals, villages in this tract, with their dilapidated houses, presented a desolate appearance. The subsoil water-table was generally deep and water sometimes brackish. The supply of drinking-water was often inadequate and inhabitants of many of the villages suffered from guinea-worm. The necessity for alleviating these conditions was prominently brought to notice by the famines of 1876 and 1899 and, as a result, the Deccan Canals were constructed. These are fed from huge reservoirs in valleys of the Ghats. There are at present eight major canals, constructed at different periods from 1875 to 1929, and they now command about 870,000 acres.

Before these canals were constructed the agriculture of the tract was simple: *bajri* (*Pennisetum typhoideum*) was grown when the early rains were good, *jowar* (*Andropogon sorghum*) if the late rains were successful. An assured supply of water, however, connotes intensive agriculture, which would be totally different from that practised under pre-canal conditions, because from the standpoint of the best utilization of the perennial supply of water throughout the year the introduction of long-term crops is essential. From the standpoint of climate sugar-cane was considered to be the most suitable crop, and its cultivation was therefore encouraged.

In the beginning there was very little information available as to the method of sugar-cane cultivation best suited to this tract. The local cultivator was quite ignorant of irrigated agriculture and, being very poor, he lacked the requisite capital. He was therefore glad to rent his land to those who could take advantage of this change, and as a result tenant cultivators increased in number, who naturally had no interest in the land and were keen on getting out of it the maximum benefit within the period of their lease by excessive irrigation and heavy manuring

without taking care to maintain soil fertility. It was thus realized that although this tract is capable of producing phenomenal yields, the cost of production was much higher than in northern India. This acted as a limiting factor in the expansion of the area under sugar-cane. Meanwhile, the Department of Agriculture in the Bombay Province established an experimental station at Manjri near Poona in 1892 which, after a great deal of field experimentation, evolved in 1911 a method now known as the standard Manjri method. Its recommendations, such as deep ploughing, planting in furrows 4 ft. apart, reduced seed-rate, reduced manuring, and irrigation, did result in some saving in the cost of cultivation which, however, remained still higher than that in northern India. Owing to the considerable variations in soil and climate, some of these recommendations were also found to be inapplicable to the tract as a whole. It was therefore considered that besides field experimentation some fundamental researches on both soil and plant were essential, and, as a result of a grant from the Imperial Council of Agricultural Research, a sugar-cane research scheme was started in June 1932 at Padegaon on the Nira Right Bank Canal. The experimental results of the last 8 years are summarized in the following pages.

I. Soil Investigations

(*a*) *Soil classification.* The soil problems were mainly concerned with the maintenance of soil fertility under perennial irrigation. It was observed that, after several years of cane-growing, the soil frequently suffered a 'loss of heart', which was reflected either in the progressively increasing quantities of manure that had to be added to maintain yields or in the increased cultural operations required to restore soil tilth. This type of deterioration was quite distinct from the infertility caused by waterlogging and salt-efflorescence.

The causes of this phenomenon clearly lay in the trying conditions imposed on the soil under cane-growing, which is here accompanied by copious irrigations to an extent of 120 to 140 acre-inches per annum applied to land accustomed to receive an annual precipitation of only 18 to 25 in. The investigations on soil, therefore, involved tracing, step by step, the changes occurring in the soil due to various factors, individually and collectively, and the detection of those causes which were directly responsible for soil deterioration, with a view ultimately to build up a comprehensive schedule of agricultural operations which would ensure the production of high yields of cane for many years.

In drawing up a programme of research, the question of classifying the soils of the tract naturally came first, as it was generally realized that different soils would behave differently under cane-growing, and would vary in their capacity for withstanding the effects of continued cultivation. A survey and classification of the soils was, therefore, undertaken and, so far, has been completed over four canals. In this classification the well-known modern genetic method, based upon the examination of the soil profile, was employed. The results of this survey led to the identification of eight distinct types named *A* to *H* [1] differing in their profiles both morphologically and physico-chemically. The study

has brought out the predominant influences of topography, drainage, and subsoil water-table as important soil-forming factors under Deccan conditions where the climate and the parent rock are more or less alike. From a consideration of all their properties, a new name, 'immature tropical chernozems', has been proposed for these soils in the world-group of soil classification. The more important of these types have been taken up for further detailed studies in pots, lysimeters, and at sub-stations situated in those canal areas where these soil types largely prevail, in order to work out systems of crop husbandry suitable to these different soil types. To simplify the genetic method for a large-scale soil survey a scheme for an experimental survey of 1,000 acres of land has been adopted on two factory estates.

(*b*) *Soil fertility studies.* Simultaneously with the genetic survey a fertility survey of the soils of the tract which had been under cane-growing on the older canals for many years past was started, and detailed information regarding the history of manuring and cane-yields was collected from various cultivators. It may be explained that as the cultivation of sugar-cane requires considerable outlay and incidental expenditure, it has to a large extent assumed the nature of commercialized farming in the Deccan, and even the average farmers in the canal areas are of a more progressive type than those in the less developed areas. Consequently, the collection of such information was less difficult than would be expected on ordinary farms. From this information the soils were grouped into two classes, deteriorating and non-deteriorating, the criterion being the calculated quantity of nitrogen required to produce a 40-ton per acre crop of cane in successive years. Detailed studies of the changes which had proceeded in these soils were determined by analysing representative samples drawn from these fields, and also of samples from adjacent land where no cane had been grown. A vast amount of data has thus been collected which has yielded very valuable information regarding the changes occurring under cane-growing and of the conditions which attend soil exhaustion. It has shown that soil deterioration is not inevitable, but that soils actually develop very appreciably as a result of cane-growing. In the main, the level of plant-nutrients, such as nitrogen and phosphoric acid, increases, the biological condition improves, and the inherent capacity of the soil to sustain crops, as shown by the improvement in the soil colloid, also increases (Table 1).

Soil deterioration was seen to be a temporary effect brought about mainly by insufficient periods of rest from cane-growing, and is thus of vital interest in maintaining soil fertility. Another important factor is the excessive applications of bulky organic manures, which leave large residues due to incomplete decomposition under these conditions, resulting in the widening of the C/N ratio and indicating an unfavourable condition for the decomposition of further applications of manure. The moral which emerges from the foregoing is that soil fertility under cane-growing can be successfully maintained with properly evolved methods of agricultural practice.

Complementary to these studies a series of field experiments was

TABLE 1. *Effect of Irrigation and Cane-growing on the Physico-chemical Properties of Soils. Godavari Canals*

Soil properties	*Godavari Right Bank Canal*		*Godavari Left Bank Canal*	
	No. of soil pairs	*Average loss or gain*	*No. of soil pairs*	*Average loss or gain*
Exchangeable calcium	40	+1.25	56	+1·27
Exchangeable sodium	42	−0·51	56	−0·38
pH in water	40	−0·03	56	−0·054
pH in N.KCl	40	−0·02	56	−0·078
Soluble salts, total	40	..	56	−0·029
Calcium carbonate	40	−0·92	56	−0·51
Clay	36	+4·40	50	+2·08
Silt	36	−0·96	50	−0·82
Humus	42	−0·12	56	−0·10
Nitrogen	40	+0·001	56	+0·011
Phosphoric acid available	40	+0·001	56	+0·003
Rate of increase in electrical conductivity	40	+4·38	56	+20·14

laid out on the station farm, situated on the *B* type of soil. From figures of successive cane-yields over a number of years it was observed that under a 3-year rotation with 150 lb. N as top-dressing the yields were maintained intact, whereas in the continuous cane-treatments a much higher dose of N (350 lb.) was required to maintain yields at a fairly constant level. In ratoon plots, on the other hand, where only 100 lb. N was applied there was a definite decline in yields (Fig. 1). These results support findings of the soil-fertility survey that the maintenance of fertility depends on providing adequate periods of rest from cane-growing. Experiments with different systems of fallow showed that for recuperation of soil nitrogen a covered fallow is the most efficient. Irrigation encouraged the growth of leguminous weeds in this soil, among which one locally called *patada shevra* (*Desmodium diffusum*) was subsequently isolated and tried as a green-manuring crop. In a large-scale replicated experiment the effect of important rotational and green-manuring crops on the succeeding crop of sugar-cane was studied, and the yields of cane following these were found to be in the order of *patada shevra* > *sann* (*Crotalaria juncea*) > fallow > cotton > ground-nut > *jowar*. Investigations with various manures in uncropped plots, which were irrigated as under cane, showed that nitrogenous manures were made available within 6 months, whereas there was a considerable amount of fixation of potassic and phosphatic fertilizers. Curiously enough, farm-yard manure showed poor nitrification under these conditions. This non-response of farm-yard manure was further studied bacteriologically in pots; it was found that full soil saturation such as occurs in a cane-field was unfavourable for bacterial growth as well as for mineralization of nitrogen, whereas half-saturation favoured both these activities.

(*c*) *Alkali soil investigations.*—Another specific problem which has been investigated by the Soil Section of the station concerns the nature

and origin of certain alkali soils of the tract, and their amelioration. These soils are found to occur either in low-lying situations or in places where salts accumulate in the profile owing to an impervious subsoil. Various types of alkali soil have been observed but, in general, they all

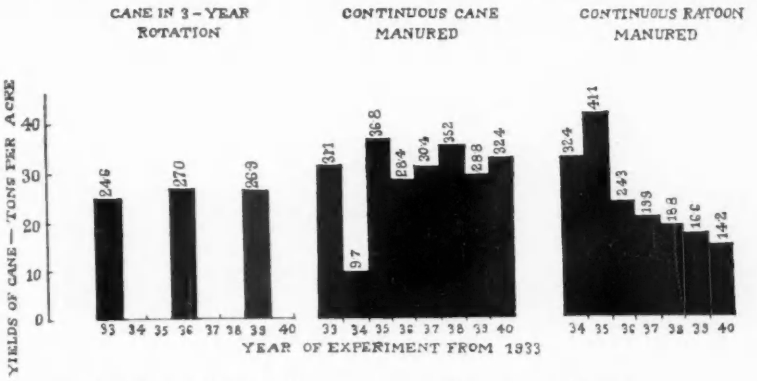


FIG. 1. Cane yields in different years in continuous-cropping systems.

show a high degree of sodium base saturation of the surface-soil and a zone of accumulation of soluble salts. Experiments conducted on one of these types occurring on the farm show that all the factors of cane-growing improve the soil condition as measured by lowering of the sodium saturation of the complex. Besides cane, crops like *berseem* (*Trifolium alexandrinum*), *dhaincha* (*Sesbania aculeata*), cotton, and rice are found to lower the sodium saturation to a considerable extent (Table 2).

TABLE 2. *Reduction in Sodium Saturation of the Soil due to Various Treatments. Heavy* (chopan) *Soil*

Treatment	*Reduction in sodium saturation after 4 years* %	*Treatment*	*Reduction in sodium saturation after 1 year* %
Water 95 acre-in. per annum	17·64	Berseem	19·5
Farm-yard manure . .	58·21	Dhaincha	14·3
Superphosphate . . .	34·38	Cotton .	10·8
Sulphate of ammonia . .	35·10	Rice .	10·7
Cane (manured) . . .	45·30	Wheat .	4·8
Cane (unmanured) . .	35·60	Rabi jowar	8·7

Summer fallowing of these soils was proved to be harmful, as soluble sodium salts move upward by capillary action during this period and thus effect alkalization of the surface-soil. Growing of lucerne and *shevri* (*Sesbania aegyptiaca*) during summer seems to be a successful method of checking this harmful rise of salts. In another experiment artificial reclaiming agents like sulphur, gypsum, farm-yard manure,

and molasses were tried, and very quick results were obtained by the use of ½ ton sulphur with 5 tons farm-yard manure. Molasses at the rate of 5 tons per acre also gave satisfactory results. The ultimate conclusion which was, however, drawn was that artificial reclamation is not essential unless the soil is actually more or less barren due to alkalinity, and that cane-growing, with proper precautions, is capable of ameliorating such soils. Trials of modified agricultural methods to suit these soils are in progress on various sugar-factory estates with the co-operation of their respective authorities, and have given promising results. A survey of such land to classify different types of alkali soils has also been undertaken, and laboratory methods of determining their suitability for irrigation are being worked out. The successful conclusion of these results will be instrumental in bringing under irrigation an extent of land estimated at 20 to 25 per cent. of the total irrigable area.

II. Plant Investigations

(*a*) *Varietal trials.*—Sugar-cane varieties are supplied for trial by the central breeding-station at Coimbatore, and so far 76 thick and 49 thin seedling-cane varieties have been received. Besides these, 96 varieties have been received from Hebbal (Mysore), where the breeding of thick seedling-canes is also in progress. Only about a dozen setts of each of these seedling-canes are sent by these breeding-stations, and the first year is utilized mainly for their multiplication and acclimatization. Thorough testing of these varieties takes a minimum period of 4 years and a maximum period of 7 years before a variety is definitely proved to be suitable for being released for trial in outside centres by sugar-factories and cultivators. These outside trials also serve as propaganda among the sugar-cane growers. So far, seven varieties have been released as promising; their performance is given in Table 3 in comparison with Pundia and P.O.J. 2878.

Table 3. *Relative Yield-performance of Sugar-cane Varieties. Mid-January Planting. Basal Green-manuring with* 150 *lb. N as Top-dressing. Tons per acre* (*Average of Three Seasons*)

	Pundia	*P.O.J. 2878*	*Co. 360*	*Co. 413*	*Co. 419*	*Co. 414*	*Co. 421*	*Co. 426*	*H.M. 320*
Cane	29·5	34·1	33·0	45·1	48·6	39·7	43·1	48·3	37·5
Sugar (C.C.S.)	3·6	4·9	4·5	5·6	6·6	5·5	5·2	5·6	4·4
**Gul*	3·4	4·0	3·8	4·7	5·6	4·4	4·2	5·3	4·0
Fibre,% in cane	11·6	14·9	12·5	16·7	13·9	13·9	19·4	15·1	13·45
Period of maturity, months	12½–14	11–12	12–12½	12–13	12–13	12–12½	11½–12½	12½–13½	12½–14

**Gul* = gur, jaggery.

Note.—The figures for c.c.s. are obtained by calculation; gul yields are the actual yields obtained per acre.

Among all these varieties, Co. 419 is outstanding and, since its release

in 1936, it has spread rapidly in general cultivation; it now occupies 70 per cent. of the area in the estates of sugar-factories and about 50 per cent. of the total area under cane on the Deccan Canals. Owing to the outstanding performance of this variety, however, other varieties have not received the attention in general cultivation which they deserve, and so they have occupied a negligible area. Although Co. 413 and Co. 426 give *gul* of superior quality, almost similar to that of *Pundia*,[1] the cultivators have taken to Co. 419 (whose *gul* is of rather inferior quality and fetches a little lower price) simply because it gives a higher return per acre owing to heavier yields.

For *Adsali* (June–July) planting, the varieties Co. 419, Co. 413, Co. 421, and Co. 408 have been found suitable. The varieties of *Sali* (plant) cane Co. 413, Co. 414, Co. 421, and Co. 419, having an early flowering tendency, are much benefited by earlier planting, i.e. in October–November instead of mid-January. Tonnages equal to 110 tons per acre have been obtained with Co. 419 in *Adsali* (June–July) planting, in certain areas, whilst an average of 60 to 70 tons per acre is a very common figure. It is also found to do well on *chopan* (alkali) soil. Other suitable varieties are Co. 421 and Co. 413 [2].

(*b*) *Germination*.—Vigorous and uniform germination is very important for the agriculturist. He, lacking knowledge of the conditions for good germination, always uses a large seed-rate as a precautionary measure, and thus wastes material which could be utilized for either *gul* or sugar-making. A very careful study of all the important factors responsible for good germination was therefore considered to be of fundamental importance in the cultivation of sugar-cane. Among the climatic factors, temperatures below 50° F. are found to be detrimental to good germination. Such bad effects of low temperature can, however, be amended to a great extent by applying nitrogen in the form of sulphate of ammonia at the time of planting. Further, rapidity of germination is found to be predominantly influenced by temperatures, which when optimum even mask the effect of the chemical constituents of the planted material. The advantages of speedy germination are twofold. It leads to increase in the final percentage germination. Secondly, the shoots of the early germinated buds are vigorous and thus able to withstand borer-attack to a great extent.

To secure the best germination it has been found necessary to adjust the method of planting according to the soil type. Although the existing method of pressing the sett by the foot into the wet soil is suitable for lighter soils, dry planting with slow irrigation improves the germination greatly in heavier soils. Buds with dry scales are very slow to germinate (Fig. 2). The great variability in germinative capacity observed in the different varieties is mainly due to the presence of different proportions of dry-scaled buds in these varieties, and, with the elimination of these from the planting material, germination has been observed to be much more uniform. It would, however, be possible to improve the germination of these dry-scaled buds by soaking them in saturated lime solution for about 24 hours.

[1] A thick, introduced cane of uncertain origin.

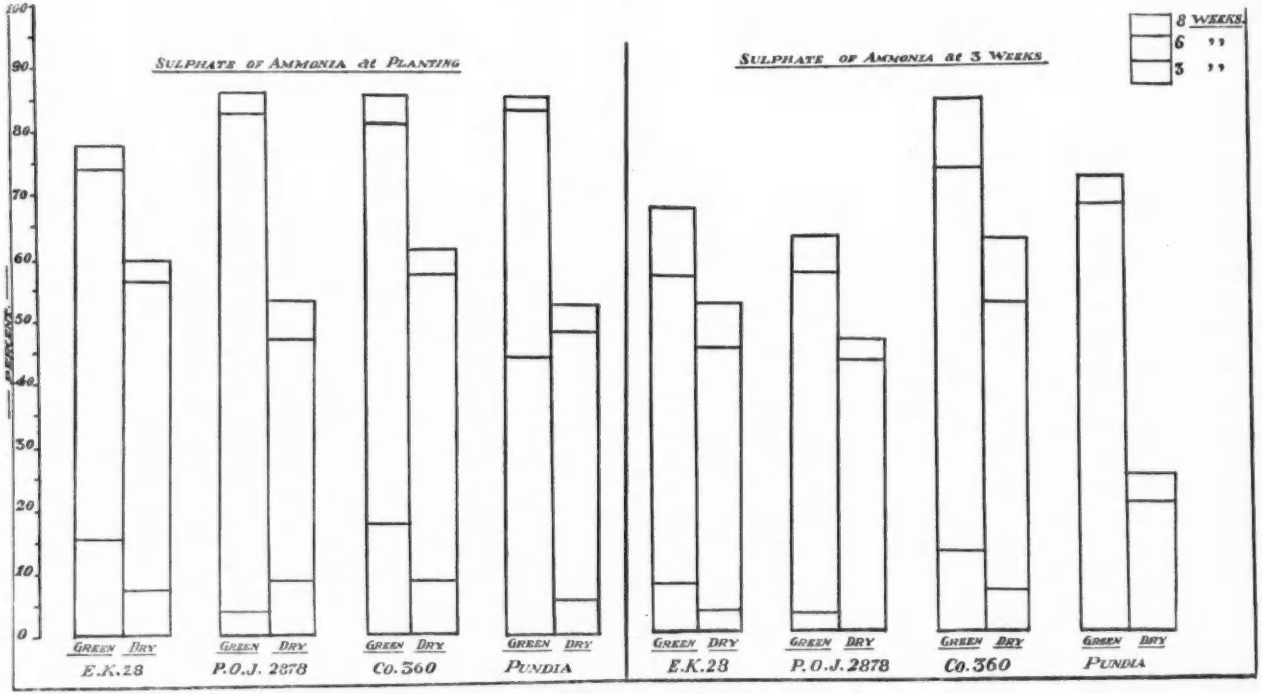


FIG. 2. Green *v.* dry scaled buds (periodical germination).

The present system of considering the age of the planting material as the main criterion for the proper selection of setts is not found to be so useful as its chemical composition, for even young canes grown with little nitrogenous manure are found to germinate slowly. Of the two important chemical constituents required for germination, viz. carbohydrates (mainly glucose) and the soluble nitrogenous compounds, the latter has been found the more important, and has actually given a positive correlation, whilst no such relation has been observed with the former. This absence of satisfactory relationship with glucose seems to be due to the irrigated system of planting, where the high moisture-content of the setts (as invariably associated with high glucose-content) is not likely to be of importance. As a practical example of the importance of nitrogen in germination may be cited the beneficial effect of applying sulphate of ammonia at planting-time, which is found to be significant, especially under unfavourable conditions of soil, climate, or seed-material. It is obvious, therefore, that in order to secure suitable planting material it is not necessary to have specially late plantings, which are generally highly susceptible to subsequent borer-attack, but normal plantings that are heavily manured with nitrogenous top-dressings, i.e. 300 lb. N and above [3].

(*c*) *Water-requirement.*—In the Deccan Canal tract, owing to the scarcity of rainfall, sugar-cane is entirely grown on irrigation, the crop receiving 36 to 38 waterings within a period of 12 months. It has been observed that on account of the ready availability of canal water and ignorance about the exact water-requirement of the crop, the cane-grower is often inclined to over-irrigate; this not only leads to considerable wastage of water, but in course of time results also in serious damage to the soil from waterlogging and salt-efflorescence. It has been estimated that during the last 40 years about 35 per cent. of the irrigable area on the older canals has been rendered unfit for cultivation owing to waterlogging and salt-efflorescence. Further, excessive watering brings in its train the need for high manuring which considerably increases the cost of cane production. It was therefore realized that a thorough investigation into all the factors which affect the water-relationships of the plant and determine the effect of water on the soil was required in order to determine the exact requirement of the crop. In the case of sugar-cane, which is generally heavily manured, two important problems arise, viz. (1) the water-requirement of a normal crop with a view to spreading the water on a maximum area, and (2) the inter-relationship of water and manure in order to secure the maximum possible yield. One of the difficulties in accurately estimating the water-requirement of any crop under field conditions was the loss of water by seepage through irrigational channels. This difficulty has been overcome in this investigation by carrying the water straight to the experimental plots through suitable Hume pipes and distribution-tanks of reinforced cement-concrete fitted with quick-opening outlets. For measuring the quantity of water, Leeds differential rotary water-meters, which measure the quantities of water to a minimum of 10 gallons, are used. The irrigation system is illustrated in Plate 1.

The first series of experiments was conducted for three seasons (1933–6), with four total quantities of water, viz. 70, 95, 120, and 130 acre-inches, inclusive of rainfall, applied in uniform doses at intervals of ten days within a period of 12 months, and with a nitrogenous top-dressing of 150 lb. N common to all. Among these, 95 acre-inches has been found to be the optimum quantity, quantities above 120 in. proving to be definitely injurious to crop-growth and leading to reduced cane-yields. This adverse effect of heavy irrigation has been traced to the leaching down of soluble nutrients beyond the feeding-range of crop roots, and to the checking of the activities of nitrifying bacteria, which affects the availability of oil-cake applied at earthing-up and thus necessitates higher manuring in order to maintain growth at later stages. On the other hand, although during the experimental period there had been no obvious reduction in final cane-yield with 70 in. of water, the rate of growth has been rather slow in this treatment. The moisture-content of the soil has also approached the wilting-coefficient stage during the early 'grand period', and the dose per irrigation has not been sufficient to bring the soil mass within the root-zone to its maximum water-holding capacity (Table 4).

TABLE 4. *Water Experiments. Average Soil Moisture (per cent. on oven-dry basis). 0–36 inches*

Stage of crop-growth		*Treatments*			
		170 in.+150 N	*95 in.+150 N*	*120 in.+150 N*	*130 in.+150 N*
Formative	1	39·6	41·5	42·9	43·6
	2	37·5	37·6	37·9	39·4
Grand period (before earthing up)	1	36·8	39·7	40·7	41·3
	2	31·2	35·7	35·8	36·7
Grand period (after earthing up)	1	38·6	40·9	42·8	41·3
	2	35·5	38·5	37·8	37·7
Flowering	1	41·1	41·9	43·2	41·9
	2	38·8	40·0	41·2	40·6
Maturity	1	41·6	44·4	45·4	44·3
	2	40·6	41·8	43·2	43·5

Note.—1 = 3 days after irrigation; 2 = day before irrigation.

The final success of so low a quantity will therefore largely depend on the amount and distribution of rainfall, which, however, cannot be depended upon in the tracts concerned. In the flowering varieties, however, there is a continuation of growth in this treatment even during the flowering and maturity period owing to a lower intensity of flowering and, as a result, no obvious reduction in tonnage was observed at the time of harvest, but owing to the delayed growth the sucrose-content was decidedly lower. The treatment with 120 acre-inches resembled that with 95 acre-inches throughout, both in the fluctuations of soil moisture and growth-behaviour, and the higher quantity of water given in this treatment is therefore practically wasted. On the whole, therefore, 95 acre-inches may be said to be the optimum water-requirement

under this manurial dose and with existing cultivation methods. Further experimental work with different irrigational systems has indicated that there is a possibility of still further reducing the water-requirement, if during the germinative and formative stages the irrigation-water is applied in alternate furrows only, instead of in every furrow as at present. The use of the alternate-furrow method during the growth-period has, however, been detrimental.

The moisture studies have shown that the water-requirement of the crop is not constant throughout the life-cycle of the plant, as it varies according to the climatic conditions and the stage of the crop. It is especially at its maximum during the rapid growing-period, i.e. mid-May to end-October, and at its minimum during the maturity stage. Within these months, the periods between mid-May to end-June, and the month of October, are those of highest water-requirement. With the approach of early monsoon conditions, the plant starts rapid growth and consequently there is an increased demand for water until changed climatic conditions, e.g. a considerable increase in humidity and decrease in maximum temperatures, are established with the actual break of rains. During October it increases as a result of decrease in atmospheric humidity following the cessation of rains. A constant period of 10-day interval with fluctuating quantities of water will, therefore, be a suitable distribution for soils with depths below 18 in.; and the adoption of this method has given much better yields (Table 5, last treatment). For shallower soils the application of smaller irrigation doses at intervals even shorter than 10 days will be beneficial.

Further experimental work on the inter-relationship of water and manure showed that although increased yields could be obtained with higher nitrogenous top-dressings, the actual water-requirement of the crop under all these manurial treatments has been practically the same, i.e. 95 acre-inches (Table 5).

TABLE 5. *Water Experiments. Yield Data*
(*Average of Three Seasons*)

	P.O.J. 2878		*Pundia*	
Treatment	*Average yield. Tons per acre*	*Sucrose in cane* %	*Average yield. Tons per acre*	*Sucrose in cane* %
95 in.+225 N	37·38	15·08	47·48	12·38
130 in.+225 N	38·62	16·02	43·64	13·12
95 in.+300 N	43·45	14·20	48·69	12·41
130 in.+300 N	44·66	15·28	47·71	12·58
95 in.+225 N (periodical)	40·11	15·01	47·58	12·55
SE.	1·4	..	1·4	..

Distinct evidence has also been obtained that, although with shallow-rooted varieties, e.g. *Pundia*, higher irrigation demands more manuring to secure the same yield as with lower irrigation, yields with deep-rooted varieties have been similar with both the waterings, irrespective

of the total quantity of nitrogen applied. From the standpoint of maturity, however, lower watering (95 in.) definitely delays it when manuring is heavy. This is found to be due to the presence of assimilable nutrients in the soil, even after the plant completes its rapid-growth period, and removal of these from the root-zone has been effective in hastening it. Thus it would seem that, although even in heavier manuring a total quantity of 95 acre-inches will suffice from the standpoint of tonnage, some higher amount of irrigation-water will have to be given in these treatments during the ripening period to leach down the nitrogen, even though the water-requirement is very low at this period. Work is in progress to find out the exact quantity required for this purpose.

(*d*) *Manurial requirements.*—A large part of the expenditure on cane-growing in the Bombay-Deccan is incurred on manuring, and this is considered to be mainly due to the tendency of sugar-cane growers both to over-manure and over-irrigate their crops. As the soils of the tract are proverbially poor in nitrogen, nitrogenous fertilizers are mainly used. There is also a custom of applying 20–30 tons of farm-yard manure at the start. The main function of this bulky material is considered to be the improvement of tilth, and its nitrogen-content is not taken into consideration in the nitrogenous manuring of the crop, which is supplied in top-dressings of 450 to 600 lb. of nitrogen as oil-cake and sulphate of ammonia, although 200–250 lb. of nitrogen is added in the farm-yard manure alone. The nitrogen in the latter is, however, found to be practically unavailable to the plant owing to extremely slow nitrification due to the high moisture-content of the soil kept up by constant irrigations. The belief that this bulky material is not a nitrogen-supplier seems to be correct. The danger of the current system of indiscriminately heavy application of this material is, therefore, evident, as it is likely to increase the C/N ratio, which in fact has happened in certain areas on the older canals that lacked good drainage. From this standpoint a dosage not exceeding 10 tons is found to be safe. As farm-yard manure is very scarce in this tract, a simple method of converting sugar-cane trash into compost has been evolved, and one acre of sugar-cane produces trash sufficient to provide about half the quantity of the required bulky material. Further experimental work is in progress to ascertain whether there is any necessity for applying farm-yard manure, especially when it does not contribute to the nutrition of the crop. The results so far achieved have shown that where a nitrogenous top-dressing is applied in the form of sulphate of ammonia, either wholly or in major quantity, a basal dose of this bulky material is quite essential. On the other hand, in treatments where this nitrogen is supplied in a similar way by oil-cakes, this basal application can be omitted.

For top-dressing, quantities varying from 75 to 600 lb. nitrogen have been tried, and the results show that about 300 lb. nitrogen is the optimum dosage when considered from all standpoints, such as tonnage in cane as well as sugar, and the percentage uptake of nitrogen applied (Fig. 3). It will be seen that, although with higher nitrogenous manuring a little higher tonnage is obtained, there is a fall in the sucrose-content as well as in the percentage nitrogen utilized. With a late-maturing

variety like *Pundia*, reduction in sucrose-content is evident even with 300 lb. N. Further, whereas in lower nitrogenous top-dressings, i.e. up to 225 lb. N, the proportion of sulphate of ammonia to oil-cakes can be equal on the N basis, the maintenance of the same proportion

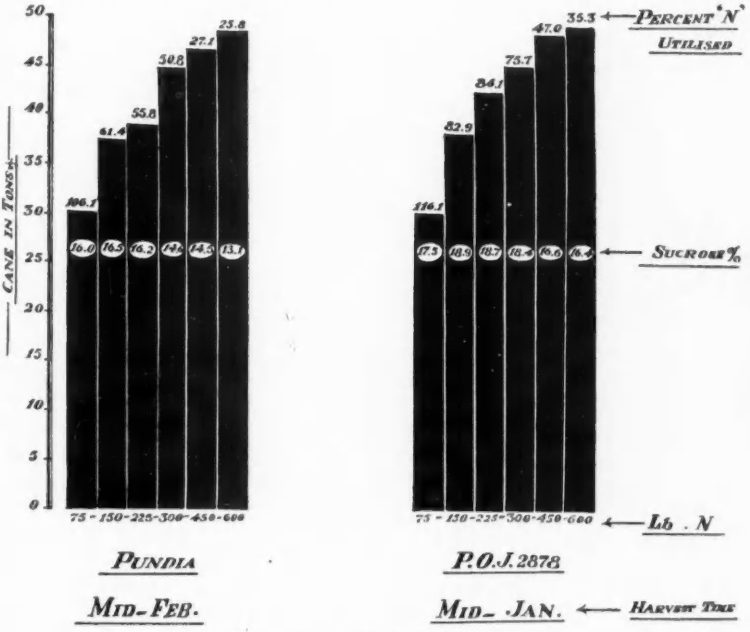


FIG. 3. Manurial series. Harvest data.

in higher top-dressings increases the concentration of soil solution, which is found to be deleterious to some varieties. Reduction of the quantity of sulphate of ammonia to one-third of the total dose is therefore advisable. The needs of the plant for nitrogen as well as other elements vary during its life-cycle, being least during the formative stage and highest during the 'grand period' stage. The existing system of applying a major quantity of top-dressing at early stages when it is not required is found to be defective, as it leads to the leaching down of nitrates by irrigation, and an improved system of manuring based on these findings has shown a decided superiority under field experimentation.

Among the other mineral constituents there does seem to be a restricted response to phosphatic manuring, as a few soil types show its deficiency. It has also been observed that even these soil types, if already under sugar-cane for many years under the cultivator's system of manuring, do not respond to phosphate owing to its gradual accumulation in the soil from the oil-cakes used in manuring. Where a response

has been obtained, application at the time of planting is best; its effect is found to be not so much on the growth of cane as on the initial stage of its life's activity; it stimulates early vigorous tillering and results in the production of a large number of canes. Further, periodical analysis of exudates has shown that the availability of soil phosphate increases as the crop grows, and this seems to be the reason why later applications of phosphate have given no favourable effect either on growth or maturity. When, however, it is supplemented by potash, an acceleration of both growth and maturity is observed, especially with heavy nitrogenous top-dressings. Further, potash alone is found to improve the keeping-quality of cane, and also to reduce the pith-formation, which is very common in P.O.J. 2878, although ordinarily there does not seem to be any deficiency of this constituent in the soil from the standpoint of plant-growth.

(*e*) *Bio-climatic*.—The statistical interpretation of 6 years' data of periodical growth and meteorological factors has clearly brought out the importance of atmospheric humidity, which is rather defective in this tract. The redeeming feature, however, is the capacity of the crop to create its own humidity thanks to the prevalent system of irrigation, which for large blocks of sugar-cane is found to be as much as 15–20 per cent. higher inside than outside the crop. Certain varieties, e.g. *Pundia*, H. 109, and E.K. 28, are found to be more susceptible to environmental factors than P.O.J. 2878, Co. 419, and Co. 413. Detailed investigation on the inter-relationship of growth, meteorological factors like temperature and humidity, and soil moisture, have shown that with optimum soil moisture, humidity determines the rate of growth. As the moisture-content begins to fall below this figure, the effect of humidity is not so very appreciable.

Acknowledgement.—The writer wishes to thank Dr. J. K. Basu, Soil Physicist, for his help in writing the section relating to soil investigations.

REFERENCES

1. J. K. Basu and S. S. Sirur, Soils of the Deccan Canals, I. Genetic Soil Survey and Soil Classification: Nira Right Bank and Pravara Canals. Indian J. Agric. Sci., 1938, **8** (Pt. V), 637–97.
2. B. P. Vagholkar and N. B. Patwardhan, Sugar-cane Varietal Trials in the Deccan Canal Tract at Padegaon, 1933–8. Ibid. 1940, **10** (Pt. V), 716–49.
3. R. D. Rege and P. V. Wagle, Problems of Sugar-cane Physiology in the Deccan Canal Tract, I. Germination. Ibid. 1939, **9** (Pt. III), 423–48.

(*Received October* 23, 1941.)

Layout of the irrigation system

PINING IN SHEEP: II. CONFIRMATORY EXPERIMENTS ON ITS CONTROL BY COBALT-RICH FERTILIZERS

JAMES STEWART

(Animal Diseases Research Association, Moredun Institute, Gilmerton, Edinburgh)

AND

R. L. MITCHELL *and* A. B. STEWART

(The Macaulay Institute for Soil Research, Aberdeen)

In a recent communication by the authors [1] it was shown that, on a farm in Easter Ross, where pining in sheep is a severe loss to flock-masters, this disease could be cured and prevented by top-dressing the herbage with a cobalt-rich fertilizer at the rate of 2 lb. of cobalt chloride per acre. Since this finding might have far-reaching effects on the technique of grass management in that district, it was decided to conduct during 1941 further, and if possible confirmatory, experiments in which a larger number of experimental animals would be used, since in the previous experiment the control and experimental groups of lambs each numbered only 15. It was therefore arranged that in 1941 a field of 12 acres should be set aside for the experiment in addition to that of 6 acres which was used in 1940.

The 12-acre field was in third-year grass, and the soil, formed on Boulder Clay derived from Old Red Sandstone, is very similar to that in the 6-acre field used in the 1940 experiment. Preliminary examination of the soil showed it to have reasonably satisfactory contents of the major plant-food substances. Just as in the case of the 6-acre field, it appeared unlikely therefore that any deficiency, which might exist in the pasture, would be directly associated with shortages of these plant-food substances. In the first week of May the field was divided by a fence into two equal parts. One half, called the 'Experimental Half', was given a top-dressing of 1 cwt. sulphate of ammonia, 3 cwt. superphosphate, and 2 lb. cobalt chloride ($CoCl_2.6H_2O$) per acre, whilst the other half, the 'Control Half', received the same dressing of sulphate of ammonia and superphosphate but no cobalt. The sulphate of ammonia and superphosphate were applied separately, the cobalt for the experimental half having been mixed with the superphosphate before sowing. The 6-acre field of the 1940 experiment, fenced in two halves, was given a stimulative top-dressing of 1 cwt. nitro-chalk per acre early in May, but no further additions of phosphate or cobalt were made. The animals on experiment were transferred to this field for a short time during the course of the experiment in order that the 12-acre field might be rested.

Within a fortnight of the fields being top-dressed, a group of 35 lambs and their mothers was placed on each half of the 12-acre field. The majority of the lambs were 2 to 3 weeks old and the two lots were chosen at random from the flock, no difference being observable between the two groups when the experiment started. During the next month 8 additional young lambs, born during June, and their mothers were added to those grazing on the cobalt half of the field. After 6 weeks' grazing on

the 12-acre field, the ewes and lambs were transferred to the correspondingly treated halves of the 6-acre field. This field was grazed for over a fortnight, after which the ewes and lambs returned to the 12-acre field, where they remained till August 22, when each lamb was weighed. The relevant numerical data are set out in Table I.

TABLE 1. *Difference in Weight between Groups at August 22, 1941*

Group	*No. of lambs*	*Range of weights lb.*	*Mode lb.*	*Total weight lb.*	*Mean weight lb.*	*Standard deviation from the mean weight lb.*	*Difference in mean weight lb.*
Control	35	79–35	40–45	1,849	53	±11·40	..
Experimental	43	101–52	76–80	3,220	75	±10·14	+22

The difference in average weight between the two groups is highly significant, and a gain of 22 lb. live-weight per head by those on the cobalt-manured half of the field reflects the great benefit to be gained by this type of 'therapeutic manuring'. In considering the results it must also be remembered that included in the experimental lambs were 8 young lambs born during June, and the smallest individual weights of this group are probably theirs. In spite of the inclusion of these young lambs only 2 of the controls had a higher weight than the average of the experimental group, and only 1 in the latter was below the average of the controls. No actual case of 'pining' was observed in the experimental group, but of the 35 lambs comprising the controls 9 or 10 were in very poor condition and appeared likely to develop the more severe clinical symptoms of 'pining' at an early date.

Opportunity was taken at the weighing of the lambs to obtain samples of blood and faeces in order that the blood-picture might be demonstrated and the worm-burden assessed of lambs affected with this condition. The results of this investigation will be reported in a later article.

That the foregoing live-weight-increases are associated with an increase in the cobalt-content of the pasture following the application of a cobalt-rich fertilizer is borne out by the results in Table 2, where details are given of the readily soluble cobalt in the soil and cobalt in the pasture from various experimental areas on the farm in question. The 1940 experimental plots were laid down to study the effect of incremental dressings of cobalt on soil and pasture and have been fully described in the previous communication [1]. In this connexion, it might be pointed out that treatment 6, viz. 40 lb. cobalt chloride per acre, was applied only to 1 plot of $\frac{1}{200}$ acre and not to 2 plots of $\frac{1}{50}$ acre, as erroneously stated previously. The readily soluble cobalt in the soil is the amount soluble in dilute acetic acid, and is probably fairly representative of the amount available to plants. These results and the cobalt-contents of the pasture, all of which are expressed in parts per million, were determined spectrographically by an arc method after chemical pretreatment.

TABLE 2. *Cobalt-contents of Soil and Pasture on July 4, 1941*

Area and treatment	*Readily soluble cobalt in soil p.p.m.*	*Cobalt in pasture p.p.m.*
12-acre field—Control Half no cobalt	0·10	0·08
,, ,, —Expt. Half 2 lb. $CoCl_2.6H_2O$ in May 1941	0·13	0·27
6-acre field—Control Half no cobalt	0·10	0·09
,, ,, —Expt. Half 2 lb. $CoCl_2.6H_2O$ in July 1940	0·15	0·16
1940 Experiment Plots Treatment given March 1940		
No cobalt	0·17; 0·16	0·08; 0·10
1 lb. $CoCl_2.6H_2O$ per acre (= 0·125 p.p.m. Co)	0·25; 0·22	0·07; 0·15
2 lb. $CoCl_2.6H_2O$ per acre (= 0·25 p.p.m. Co)	0·24; 0·31	0·22; 0·28
10 lb. $CoCl_2.6H_2O$ per acre (= 1·25 p.p.m. Co)	0·61; 0·90	0·63; 0·57
40 lb. $CoCl_26.H_2O$ per acre (= 5·0 p.p.m. Co)	4·5	1·90
80 lb. $CoCl_2.6H_2O$ per acre (= 10·0 p.p.m. Co)	4·9	3·20

The first part of Table 2 gives results obtained with samples taken from the 12-acre field 2 months after the application of the fertilizer dressings. In the remainder of Table 2 the results are for samples taken more than a year after the treatments described in the previous communication [1] were applied. From the results for the 12-acre field it will be seen that, as observed last year, the application of 2 lb. cobalt chloride per acre brings about a marked and speedy increase in the cobalt-content of the herbage. The application of the fertilizer dressing is also reflected, though less strikingly, in the content of readily soluble cobalt of the soil. Although cobalt chloride as a fertilizer is rapid in its action, it is obvious from the results in the other sections of Table 2 that its effects last for a considerable period and that even after 15 months it has a considerable residual effect. This is borne out by the figures for both soil and pasture.

Further results on the residual value of cobalt fertilizers and on the relative uptake by various pasture species of cobalt from manurial dressings are being obtained and will be reported later.

It is suggested, in the light of the above experiment, that on farms where pining due to cobalt-deficiency occurs, the benefits to be gained by top-dressing with cobalt-rich fertilizers are well worth while, and the flockmaster would be amply repaid by the increase in live-weight and general improvement in condition of his lambs for his initial outlay on the fertilizers. Before applying a cobalt-rich fertilizer for the purpose of preventing 'pine' due to cobalt-deficiency, it is important to make sure

that such deficiency actually exists, as 'pining' may be due to several causes, and it is only when the causal factor is cobalt-deficiency that the farmer would obtain any benefit from the use of cobalt-rich fertilizers.

Acknowledgements.—The authors acknowledge with thanks the most helpful co-operation of Mr. C. M. Allan, North of Scotland College of Agriculture, and the assistance in the analytical work of Mr. R. O. Scott (Macaulay Institute).

REFERENCE

1. J. Stewart, R. L. Mitchell, and A. B. Stewart, Empire J. Expt. Agric., 1941, **9**, 145.

(*Received October* 23, 1941)

RUBBER INVESTIGATIONS IN CEYLON

T. E. H. O'BRIEN

(*Director, Rubber Research Scheme, Ceylon*)

WITH PLATE 2

EARLY investigations on Rubber (*Hevea Braziliensis*) in Ceylon were undertaken by officers of the Department of Agriculture, and the contemporary literature provides a record of valuable advances in relation to planting methods, anatomy and tapping, treatment of diseases, and preparation of the raw product.

About 1909 the Rubber Growers' Association appointed a chemist in Ceylon to assist its members, who were largely London companies, in the preparation of raw rubber; later a mycologist was also appointed. Other rubber producers, who were not members of the Association, recognized the need for scientific research and assistance and, in 1913, an arrangement was made with the Government of Ceylon and the Imperial Institute, London, whereby a scientific officer, styled the Rubber Chemist, was appointed to study certain physiological problems of the Rubber tree, and to prepare samples of rubber for examination at the Imperial Institute. In this way began the Rubber Research Scheme.

In 1920, after a period of inactivity resulting from the war of 1914–18, the local scientific work of the Rubber Growers' Association was merged in that of the Rubber Research Scheme, and the scope of the work was extended. A further important development occurred in 1930 when the Rubber Research Scheme was constituted by Government Ordinance (Chapter 302), provision being made for the incorporation of a Board of Management, and for financing its activities by a levy of $\frac{1}{8}$ rupee cent per pound of rubber exported from the island. Based on the present productive capacity of 109,000 tons the levy would yield an annual income of Rs. 305,000 (£23,000), but owing, firstly to the world economic depression, and later to the operation of the International Control Agreement, exports have been on a lower scale, and income from this source over the 10-year period has averaged Rs. 176,000 (£13,000). A cautious policy of development in the early years after reorganization led to the building up of a reserve fund, which has since enabled the Board to meet its capital expenditure from available resources.

Dartonfield Estate, comprising 175 acres of mature Rubber in the main Rubber-growing district of Ceylon, was purchased for use as an Experiment Station in 1933, and the head-quarters of the Scheme was established on the estate towards the end of 1936, after the erection of offices, laboratories, and residential quarters. In addition to Dartonfield the Board owns Nivitigalakele Experiment Station, 7 miles distant, which was established in 1926 for the testing of clonal planting-material, and has since been extended. The present planted area is 135 acres, and there is a small reserve of unopened land. Negotiations are in progress for the lease of a further square mile of Crown land for experimental planting.

According to the terms of the ordinance, the functions of the Research Scheme are, firstly, to undertake investigations relating to the production, preparation, and utilization of rubber, and secondly to afford practical advice and assistance to those engaged in the industry. The Board attaches great importance to the latter branch of work, but it has not been considered desirable to establish a separate advisory department (except for small-holders), experience having shown that the Rubber-growers prefer to make direct contact with the officers whose experimental work forms the basis of the practical advice.

Owing to the relatively limited funds available, investigations are necessarily restricted to problems of special local importance, and to the application under local conditions of the results of investigations of a more fundamental nature emanating from research institutes in larger rubber-producing centres. The relative importance of agricultural and chemical research has been reviewed from time to time, and it is the policy of the Board to undertake both branches of work, with, however, a bias on the agricultural side.

The present staff of the Research Scheme comprises seven scientific officers (including the Director), and the work is divided into the following departments: Botany and Mycology, Soils, Chemistry, Small-holdings Propaganda. Routine working of the estates is in charge of a practical planter. The Board also finances (jointly with the Rubber Research Institute of Malaya) work on the quality of plantation rubber, which is conducted at the Imperial Institute, London, under the control of the London Advisory Committee for Rubber Research (Ceylon and Malaya). In the present article it is intended to discuss the agricultural work of the Research Scheme and to refer briefly to the work of the other departments.

Botany and Mycology Department (Staff: *Botanist and Mycologist, Geneticist, Assistant Botanist*)

The two related branches of work were grouped together at a time when caution was necessary in the appointment of additional staff, and when it appeared unlikely that extensive work would be required on the mycological side. The position has changed somewhat in recent years owing, firstly, to the increased economic significance of Oidium leaf-disease, and, secondly, to an increase in the incidence of root-diseases, consequent on the extensive replanting programmes which have been undertaken on estates. The Board has recognized the desirability of appointing an additional officer for mycological work, but no steps are likely to be taken in this direction under present conditions.

A. *Botanical Work*

The work of the department consists mainly of field trials and investigations, and will be considered under the headings (1) Improvement of planting material, (2) Tapping, (3) Miscellaneous.

1. *Improvement of planting material.*—Most readers will, no doubt, be aware that the yield of individual seedling-Rubber trees varies very

markedly and that, as in other economic crops, energetic steps have been taken in the main rubber-producing countries to develop high-yielding planting material, both by sexual and asexual propagation. Already yields up to 1,200 lb. per acre, compared with an average yield of 500 lb. per acre from unselected seedling-material, have been recorded from large commercial areas, and there can be no doubt that these figures will be improved on in the future.

Work on the subject in Ceylon was started about 1924, when arrangements were made for recording the yields of a large number of high-yielding trees on local estates. Plots of bud-grafts from 130 of the best trees were established at Nivitigalakele Experiment Station during the period 1926–31, and the grafts are now under test-tapping. So far the work has resulted in the discovery of a small number of clones of outstanding promise (Table 1).

TABLE 1. *Summarized Yields of the Three Best Clones*

	Yield in lb. per tree per annum at ages of (years)						
Clone	*4*	*5*	*6*	*7*	*8*	*9*	*10*
MK. 3/2	3·0	6·0	8·7	12·2	11·7	17·0	17·7
WG. 6278	..	..	2·4	8·2	13·7	14·7	17·1
HC. 28	..	4·5	..	7·5	12·0	12·3	13·7

Concurrently with this work an area at Peradeniya was planted by the Department of Agriculture with plots of grafts derived both from local mother trees, and from the best material then available from other countries. These plots were laid out on a replicated basis, which enables critical comparisons to be made between the clones. The area is now under tapping and the records are made available to the Research Scheme. Early plantings on estates with bud-grafts from local and imported sources are also being test-tapped in co-operation with the Research Scheme. In connexion with this and other work of a similar nature the crop from about 3,000 individual trees is weighed each month at the laboratories for record purposes.

The collection of potentially high-yielding material at Nivitigalakele is now being used as the basis for breeding trials. Crosses are being made by artificial pollination between trees of the best local clones, and between those clones and the best imported clones available. The technique of the operation is not easy, since the flowers of *Hevea* are small and not readily accessible, and the flowering season is a short one. There is also the complication, particularly in Ceylon, that the flowers are liable to fall as the result of attack by *Oidium Heveae*, and the ripening fruits may be attacked by *Phytophthora palmivora*. The fertility of different clones varies very substantially, and the percentage of successful pollinations has varied in individual instances from 0 per cent. to 27 per cent. An average of 5 per cent. successes is usually regarded as satisfactory.

The seedling families derived from the crosses are being planted out

for subsequent tapping with two objects; firstly, to ascertain which clones are good seed-parents and, secondly, to discover individuals of outstanding merit from which further new clones may be derived by bud-grafting. The present plan of operations is to establish a family of 25 seedlings of each cross. When the seedlings are about a year old a preliminary indication of latex-flow is obtained by pricking the bark with the 'Testatex' knife; trials carried out by the patentee, Dr. P. J. S. Cramer, and others having shown that there is some correlation between the latex-flow under these conditions and the subsequent yielding capacity of the tree. From the best 20 per cent. of the seedlings about 5 bud-grafts are made, with material obtained by disbudding or stumping the stem, and these are planted out with the seedlings. Thus if a particular seedling is found, on test-tapping, to have an outstanding yield it will be possible, in most instances, to obtain data on the performance of its bud-grafted offspring without undue delay. The only reason for not making bud-grafts from every seedling is the large area of land which would be required for testing the material. Arrangements are being made with some estates to plant small isolated areas, in suitable locations, with the clones used in the breeding trials. At a later stage, when it has been ascertained which of them are good seed-parents, the remaining clones can be removed, and seed of the required crosses will become available for commercial use with the minimum of delay. These steps are necessary owing to the long period which is required for testing experimental material of *Hevea*.

Other countries are ahead of Ceylon in breeding-work. In Sumatra legitimate crosses of selected mother trees were made at the Proefstation der A.V.R.O.S. as early as 1919, and valuable clones derived from individual seedlings are already coming into commercial use; other clones developed from such seedlings are recommended for experimental planting. Similar work was undertaken at a later date in Malaya, and has reached a stage at which series of clones derived from high-yielding individuals are being distributed for trial on estates. In Java a number of seedling families are in tapping.

There has been considerable activity in Ceylon and other countries in the laying out of isolated seed-gardens with clones which are known or considered likely to produce good crosses, with a view to the commercial production of improved seedling-material. In two instances a stage has been reached at which substantial areas planted with such material from the gardens have been shown to produce high yields. Plots of seedlings from these gardens, the Tjikadoe seed-garden in Java and the Prang Besar seed-garden in Malaya, were established at Nivitigalakele Experiment Station some years ago and are now in test-tapping.

Material from the Tjikadoe garden is also available on a local estate, where an area of 20 acres, planted in 1928, gave a yield of 1,100 lb. per acre in the third year of tapping. After examination of the material by Research Scheme officers clones have been established from twenty-five of the most promising trees. These, together with buddings from the most promising 'second-generation' clones available from Malaya and the Netherlands East Indies, have been planted in experimental areas

established at Nivitigalakele in 1939 and 1940, and will form a useful basis for a further stage of selection work.

Commercial planting of improved material on local estates has been undertaken on a steadily increasing scale, mainly in connexion with programmes for replanting existing areas. New planting, to the extent of 5 per cent. of the existing areas, was permitted in 1939–40, under the International Rubber Control Agreement. The material used consists principally of bud-grafts of imported clones, but isolation-garden seed has been used to some extent, and limited areas are being planted with bud-grafts of the best local clones. Ceylon is relatively backward in the use of improved planting material, as shown by the figures in Table 2.

TABLE 2. *Proportion of Budded Rubber to total Acreage* (*Estates only*) (*at end of 1938*)*

Ceylon	6 per cent.
Malaya	12 „ „
Netherlands East Indies	30 „ „
French Indo-China	36 „ „

* Later figures are complicated by new planting in 1939 and 1940, data for which are not yet complete.

2. *Tapping*.—Opinions vary concerning the best method of tapping the Rubber tree as regards length of cut, intervals between tappings, &c.; indeed, it can be said without hesitation that no single method is equally suitable for trees of all ages and under all conditions of growth. Expressed briefly, the problem is to extract as much rubber as possible, at the lowest cost, without removing bark more rapidly than it can regenerate, and without unduly disturbing the physiological functions of the tree.

In the early days of the industry Ceylon producers played a prominent part in the development of tapping systems, and it is probable that the system which has been regarded as the standard one for the past 25 years originated in this country. This system consists of tapping the bark of the tree with a single spiral cut on half the circumference every second day. Various modifications have been devised in more recent years with a view, (*a*) to reducing the intensity of tapping to suit areas which require a milder system, or (*b*) to obtaining a higher yield or an equal yield at a lower cost from a system of equivalent intensity. Examples of such modifications are, (*a*) 1 spiral cut on $\frac{1}{3}$ circumference every second day; 1 spiral cut on $\frac{1}{2}$ circumference every third day; 1 spiral cut on $\frac{1}{2}$ circumference every second day with a periodic rest; (*b*) 1 spiral cut on $\frac{1}{2}$ circumference daily with a periodic rest of equal duration; 2 spiral cuts on $\frac{1}{2}$ circumference every fourth day, &c.

An experiment was laid down by the Research Scheme in a mature-seedling area at Dartonfield in 1936 to compare eleven tapping systems. The treatments are replicated sixfold and are arranged in randomized blocks. A uniformity trial carried out for 12 months before the application of the treatments enables the results to be corrected for plot variation by means of a regression on the initial yield figures. The experiment will be continued for at least a full cycle of bark-renewal (8–12 years, according to the system). So far the results are in line with general

expectations and it is not intended to discuss them in detail. The level of yield at Dartonfield is relatively high, and it is recognized that somewhat different results might be obtained from a similar experiment carried out in an area situated less favourably. It is not, however, practicable to extend the trial to other areas with the staff available.

The development of budded Rubber has raised new tapping problems. In the first place it has been shown that a single system of tapping is not equally suitable for all clones. Secondly, it must be recognized that high-yielding material is, in general, more susceptible than mixed seedling Rubber to the physiological disease known as Brown Bast, which leads to the cessation of latex-flow. Another factor of importance is that the difference in the yield of latex at different heights on the stem is less marked in the case of bud-grafts than seedlings. In seedling Rubber the yield at a height of 3 ft. from the base of the tree is approximately 50 per cent. of that at 6 in. from the base. Bud-grafts vary according to the clone but, as an average, it may be said that the fall in yield at a point 3ft. above the union does not exceed 15 per cent.

Trials have been initiated in Ceylon to ascertain the tapping systems which are best suited, under local conditions, to the clones which have so far been most extensively planted. Such trials must be undertaken on estates which have suitable material available, and the layout must be sufficiently simple to enable the data to be obtained without undue interference with estate routine. At present experiments are in progress on four estates.

3. *Miscellaneous.*—Problems relating to methods of opening and planting the land are receiving attention in co-operation with the Soils Department.

TABLE 3. *Effect on Mean Girth of Trees (inches) of Different Methods of preventing Soil Erosion, Planting, and Fertilizing*

	1940	*1941*	*Increment 1939–40*
Methods of opening			
1. Platforms	12·46	16·33	3·87
2. Trenches	12·17	15·81	3·64
3. Pitted drains	11·39	15·11	3·72
Standard error	..	..	..
Significant diff. (0·05)	Not significant		
Methods of Planting			
1. Budded stumps	12·77	16·56	3·79
2. Stumped buddings	15·33	19·04	3·71
3. Field buddings	7·91	11·65	3·74
Standard error	0·273	0·331	..
Significant diff. (0·05)	0·81	0·98	Not significant
Manuring			
1. Organic	11·92	15·67	3·75
2. Inorganic	12·10	15·83	3·73
Standard error	..	..	..
Significant diff. (0·05)	Not significant		

A replicated trial was laid out, in an area which was replanted at Dartonfield in 1936, to compare three forms of earth-works for the prevention of soil erosion. The sub-blocks were divided into plots for a comparison of three forms of planting material, and each plot was sub-divided for a comparison of organic and inorganic fertilizers. Girth-measurements after 5 years are shown in Table 3.

An area of 20 acres at Dartonfield was set aside some years ago for a study of the so-called 'forestry' system of cultivation, under which a ground-cover of naturally occurring plants is allowed to develop, in place of the now obsolete system of clean weeding, or the more conventional system of planting leguminous creepers. Periodical studies have been made of the changes in the flora, and the necessary attention has been given to the control of the covers and to the removal of undesirable species. The present position is that the area carries a useful mixed cover and that yields, after showing an initial decline, are now rather better than those in other parts of the estate. Further observations on natural covers are being made in areas at Nivitigalakele which were cleared from jungle without a 'burn-off' in 1940 and 1941.

TABLE 4. *Relative Effects on Girth of Young Budded Plants of Different Species of Cover, &c. Budded Stumps Planted in June 1934. Girth in Inches at 3 ft. from Union*

	Year				
	1936	*1937*	*1398*	*1939*	*1940*
	Age				
Treatments.	*2 yrs.*	*3 yrs.*	*4 yrs.*	*5 yrs.*	*6 yrs.*
Species of cover					
1. *Centrosema pubescens*	5·16	8·93	13·40	17·29	20·92
2. *Pueraria phaseoloides*	4·95	8·61	13·56	17·86	21·41
3. *Calopogonium mucunoides*	5·51	9·36	13·83	17·69	21·16
4. *Dolichos Hosei* (*Vigna*)	5·43	9·66	14·49	18·48	21·90
Mean	5·26	9·14	13·82	17·83	21·35
Standard error	..	0·19	0·18	..	..
Significant difference ($P = 0·05$)	Not sig.	0·64	0·61	Not sig.	Not sig.
Timber treatmens					
A. Leaving all main stems lying unburned	5·38	9·38	14·06	18·08	21·68
B. Burning all timber on the land	5·19	9·16	13·94	17·99	21·40
C. As B, but also removing and burning all larger lateral roots	5·22	8·88	13·46	17·42	20·97
Mean	5·26	9·14	13·82	17·83	21·35
Differences	Not significant				
Control of cover					
X. Keeping platforms clean weeded	5·30	9·17	13·76	17·64	21·23
Y. Ring weeding in 6 ft. diameter circle	5·22	9·10	13·88	18·01	21·46
Mean	5·26	9·14	13·82	17·83	21·35
Differences	Not significant				

The effects of four species of leguminous creepers on the growth of young budded plants were studied in an area at Dartonfield which was replanted in 1934. Subsidiary comparisons were made between three methods of dealing with the timber from the old stand of trees, and two methods of controlling the cover-crop. The trial was terminated when the trees reached tappable size, and a summary of girth-measurements is given in Table 4.

B. *Mycological Work*

1. *Root and collar diseases.*—These diseases, which commonly lead to the loss of Rubber trees in Ceylon, are caused by the following fungi: *Fomes lignosus*, *Fomes noxius*, *Ustulina zonata*, and *Poria hypobrunnea*. Diseases caused by *Sphaerostilbe repens* and *Xylaria Thwaitesii* occur less frequently. Generally speaking, the incidence of root-disease is considerably lower in Ceylon than in Malaya or Sumatra, and it has not been found necessary to undertake any major investigations in recent years.

During the replanting on estates in the past few years outbreaks of root-disease have frequently been found to occur on the young plants in areas where there was no previous history of root-disease. The source of infection can invariably be traced to an old Rubber root (or, more rarely, a jungle stump), indicating that the fungus was present before the trees were felled, but was not sufficiently active to affect the health of the trees to a serious extent. The explanation has been advanced that root-disease fungi can exist in the wood of the root-system in a state of what may be termed 'subdued parasitism'. When an infected tree is felled and the roots are left in the ground, the balance between the fungus and host is upset, and the former assumes a condition of active growth. It then needs only the contact of a young root with the old infected root for the fungus to spread to the new plant and kill it.

The treatment which has been advised is similar to that which is recommended for older diseased trees, namely, to trace out and remove all the infected material. If this is done effectively, it has been found that casualties can be replaced immediately without risk of further attack. Although the loss of young plants may be severe in individual instances, the incidence of disease under Ceylon conditions is, in general, very low and rarely exceeds 1 per cent. Another encouraging feature is that the incidence of disease in badly affected areas is usually found to diminish very substantially in the third or fourth year, provided that control measures have been carried out efficiently.

Apart from known disease patches, which must be dug over thoroughly before being replanted, it is considered more economical, under local conditions, to deal with outbreaks of disease as they occur than to undertake the general removal of the old roots before replanting, as is commonly done in Sumatra. Indeed, in many instances such treatment would be virtually impossible owing to the rocky nature of the land, and the risk of serious soil erosion on steep hill-sides. In Malaya a system of control has been devised whereby the root-systems of the young plants are opened up periodically for inspection. The system has been tried

on several estates in Ceylon and appears to be of value in special circumstances.

2. *Stem Diseases.*—These also are of little importance in Ceylon. *Ustulina zonata* and *Botryodiplodia theobromae* may cause damage if they are able to gain entrance through wounds or dead tissues. *Phytophthora palmivora* causes two forms of canker, one in the mature bark (patch canker) and a different form in the renewing tissues of the recently tapped bark (bark-rot or black-stripe canker). The latter may lead to serious damage to the tapping panel in wet weather if not controlled, but can readily be prevented by applying a diluted 'water-soluble' disinfectant fluid regularly to the tapping cut, or by smearing the cut with a water-proof base containing a suitable proportion of disinfectant. An investigation carried out in Ceylon some years ago showed that the efficiency of various disinfectants was proportional to the tar-acid content. Ceylon is fortunately free from *Ceratostomella fimbriata*, which causes a more serious disease of the tapping panel ('mouldy rot') in other countries.

A disease of the tapping panel, known as Brown Bast, which leads in the first instance to the cessation of latex-flow, is now generally accepted as being of physiological origin. Its incidence is associated with the application of unduly heavy-tapping systems, particularly tapping at too short intervals, and can usually be prevented by adjusting the intensity of the tapping system to the environmental conditions. Investigation of the cause of Brown Bast has mainly been undertaken in other countries; in Ceylon a method was developed some years ago for treating affected tapping panels by scraping away the diseased tissues. The occurrence of Brown Bast in old seedling areas is now of less significance than it was a few years ago, since it may be expected that the areas will gradually be replanted with high-yielding material. It was stated above that such material, in general, shows increased susceptibility to Brown Bast, and it is of the greatest importance to ensure that the intensity of tapping systems in young high-yielding areas is so adjusted that the incidence of the disease will be restricted to a minimum.

3. *Leaf-diseases.*—Ceylon's relative good fortune in respect of root- and stem-diseases is balanced by the occurrence of two serious leaf-diseases. *Oidium heveae* attacks the young leaflets during refoliation, causing an abnormal leaf-fall or, if the leaves are slightly older, distortion and crinkling. Leaves which are almost mature may also be attacked, giving rise to yellowish spots that gradually darken in colour. The disease has been known in Java since 1918, and an attack was reported from all the main rubber-producing countries, including Ceylon, in 1925. Since then its occurrence has been regularly reported, but it appears to have attained greater economic significance in Ceylon than elsewhere, especially in 'mid-country' areas where Rubber is planted at elevations of 1,000–2,500 ft.

The present position in Ceylon is that the disease regularly causes severe defoliation at mid-country elevations during the annual refoliation period, if control measures are not taken. In fact, in extreme cases, several successive defoliations may occur as the trees put out further new

leaves in an effort to recover. About $\frac{1}{8}$ of the total Rubber in Ceylon is located at elevations exceeding 1,000 ft., but the economic importance of this Rubber is less than the proportion indicates, since the climatic conditions are unfavourable to the crop in other respects.

In the main low-country districts the incidence of the disease in different seasons depends on weather conditions, and may vary from a mild attack on a small proportion of late-wintering trees to conditions which merge into those regularly experienced in the mid-country. Research in other countries has shown that spore-formation is favoured by relatively low temperatures and is most prolific at about 60° F. This observation provides the clue to the relative importance of the disease under different conditions. In mid-country districts in Ceylon night temperatures are always sufficiently low to favour spore-formation and the rapid spread of the infection. Somewhat similar conditions prevail in parts of Java where Rubber is planted at corresponding elevations. In the low-country night temperatures vary in different seasons, and it has been possible to correlate severe outbreaks with the occurrence of unusually low night temperatures during, or shortly before, the refoliation season. Dull, showery days, by reducing day temperatures, also favour the activities of the fungus.

Sulphur is generally recognized as the best medium for the control of fungi of the powdery mildew class, and very successful results were obtained in Java at an early stage by applying sulphur dust to the trees, by means of power-operated dusting machines. Experiments were undertaken in Ceylon with a machine of this type, and the Research Scheme gave substantial assistance in the development of a suitable dusting machine of British make.

Over a 6-year period from 1930, 30 acres of Rubber, at an elevation of 2,000 ft., were sulphur-dusted during the refoliation seasons under the supervision of the Research Scheme; yield records were kept in the dusted area, and also in an adjoining untreated field. The following general conclusions were drawn from the trials:

(1) That satisfactory, though not complete, control of the disease can be obtained at this elevation, provided abnormal rains are not experienced during the refoliation season; and that while a reasonable foliage is present the yield and rate of bark renewal are maintained at a normal level.

(2) That in the absence of control measures the yield of severely affected areas eventually falls to an uneconomic level and the trees become virtually untappable.

The beneficial effects of sulphur-dusting are clearly shown in Plates 2 and 3.

At an earlier stage trials were made with liquid spraying, using a proprietary sulphur fungicide. The results were inconclusive, and this troublesome and expensive method was abandoned as soon as a satisfactory technique for dry dusting was evolved. The value of manuring was studied in a severely affected area at an elevation of 2,000 ft., particular attention being paid to the possible nitrogen and potash effects. The results of two successive annual applications of various fertilizers

were entirely negative, and it was concluded that in severely affected areas manuring alone is of no value in the control of the disease. It is, however, considered that manuring, in conjunction with sulphur-dusting, plays an important part in maintaining the vigour of the trees.

Sulphur-dusting is now adopted as a routine procedure during the refoliation season on the majority of well-managed estates above an elevation of about 1,000 ft. Applications of 4–10 lb. of sulphur per acre are made at intervals of 5–10 days during a period of 4–8 weeks, according to local conditions. Inclusive costs amount to Rs. 4 to Rs. 10 per acre (pre-war costs), depending mainly on the quantity of sulphur used. The dusting machine most favoured in Ceylon is made locally and is operated by a 2½ h.p. engine, which throws the sulphur to a height of about 80 ft. under favourable conditions. The machine weighs 175 lb., and may be pushed along on a pneumatic-tyred trolley, or carried on poles by 4 labourers. About 100 acres per day can be dusted with one machine.

The sulphur most used locally is derived from volcanic-mud deposits in Java, but sulphur from various other sources has also been used with success. Many samples of sulphur have been examined in the laboratories in order to gauge their probable suitability for use as dusting powders. The main requirements are extremely small particle-size, and absence of tendency to cake when stored in a moist climate. Experimental work on Java sulphur indicated that excessive moisture-absorption and consequent caking was due to the presence of free acid; the producers have since adopted a method of refining which largely overcomes this difficulty. Field comparisons between different brands of sulphur have also been made.

In the main low-country Rubber districts, which are subject to a long wet season during the south-west monsoon, the control of Oidium is complicated by the fact that complete control may lead to increased susceptibility to another leaf-disease known as 'secondary leaf-fall' or 'leaf-and-pod disease', caused by *Phytophthora palmivora*. This disease first attacks the ripening seed-pods during wet weather and spreads to the leaf-stalks, causing the leaflets to fall. The connexion between the two diseases is that Oidium attacks the flowers as well as the young leaves, and its control leads to increased setting of seed, thus providing more centres for the spread of Phytophthora. It is a fact that the damage caused by Phytophthora leaf-fall in Ceylon has been considerably reduced since the appearance of Oidium, and also that areas which have been heavily sulphur-dusted may suffer much more severely from secondary leaf-fall, if weather conditions are favourable to the disease, than neighbouring undusted areas.

The policy which is recommended on low-country estates is to compromise by controlling Oidium to an extent which gives the fungus scope for attacking the more susceptible inflorescences, while preventing most of the damage to the young foliage. Estates are advised to have dusting equipment and sulphur available, but not to start dusting operations unless, or until, the foliage is seen to be attacked. In practice the compromise works well and it is common on low-country estates for 3–6 light

applications to be made, involving the total use of 10–20 lb. of sulphur per acre.

With regard to future research on Oidium, it is recognized that a systematic study of the histology of the disease might lead to results of economic value in its control, although this is by no means certain. The Research Board has decided, in principle, that such an investigation should be undertaken when, and if, funds can be made available for the appointment of an additional officer. Other lines of work which are being undertaken as time permits, are: (1) a search for strains of Rubber which are resistant to the disease. So far the results are not promising, although there are indications that some of the commonly used clones are rather more susceptible than others. (2) Tests of various substances as adhesives, with a view to preventing the sulphur being washed off the leaves in heavy rain. Preliminary inquiries on this subject are not encouraging. (3) Field trials of various grades of sulphur which might either reduce the cost or increase the efficiency of dusting.

SOILS DEPARTMENT (Staff: *Soil Chemist, and Analyst*).

The Soils Department was formed in 1938, prior to which problems relating to cultivation came within the purview of the Botany and Mycology Department. The two departments work in close co-operation, and reference has already been made to field trials relating to several problems which are of interest to both departments.

The Soil Chemist is mainly occupied, at present, with a study of the fertilizer requirements of Rubber under local conditions. Much information is available about Ceylon soils, and it is known that soil types do not show striking variations in the main Rubber districts. Generally speaking, the soils are lateritic and of gneissic origin; in two minor Rubber districts limestone belts occur. Field trials can therefore be laid down with the knowledge that the results derived from them will be fairly widely applicable. Data on soil samples examined in connexion with experimental and advisory work will form the basis on which a soils map of the Rubber districts will gradually be built up.

Fertilizer trials in young Rubber are relatively simple to carry out, since the effects of the treatments are judged by the rate of growth of the plants. When the trees reach tappable size the basis of comparison is changed to that of yield, and it will readily be recognized that special difficulties arise from the fact that the crop is harvested in small quantities throughout the year, by tapping at 2–4 day intervals, according to the system adopted. Investigations in other countries have recently shown, however, that there is no great reduction in accuracy if results are based on 'sample' yields taken at infrequent intervals. The importance of this development is that relatively complicated trials can be laid out on commercial estates, and a trained officer sent round periodically to sample the yields of the plots.

A fertilizer trial on mature Rubber was laid out at Dartonfield in 1936. Experimental treatments are 0, N, NP, NK, NPK, the fertilizers being applied in equivalent quantities as sulphate of ammonia, rock phosphate, and muriate of potash. A comparison is also made between two methods

of application, broadcasting and envelope-forking. The trial provides 8 comparisons of the fertilizer treatments and 4 comparisons of the method of application. Preliminary yield-recording was carried out for 12 months before the first application of manures. Annual applications were made for the first 3 years; the interval has now been extended to 2 years in conformity with standard estate practice. Summarized figures are given in Table 5.

TABLE 5. *Results of Fertilizers Trials on Mature Rubber at Dartonfield, 1936–40. Mean Yield in Kilograms of Dry Rubber per Plot of 20 Trees*

	Actual yield		*Adjusted yield* (*Percentage yields are shown in brackets*)			
Treatments	*1936*	*1940*	*1937*	*1938*	*1939*	*1940*
N . .	53·4	45·0	49·8 (111)	56·9 (114)	44·5 (112)	44·6 (111)
NP . .	52·3	41·5	47·5 (106)	52·9 (106)	41·5 (104)	42·0 (104)
NK .	55·5	46·6	49·1 (110)	56·5 (113)	44·1 (111)	44·6 (111)
NPK .	56·5	50·2	49·6 (111)	59·3 (119)	46·6 (117)	47·4 (118)
O . .	47·1	35·6	44·8 (100)	50·0 (100)	39·7 (100)	40·3 (100)
Mean .	53·0	43·8	48·2	55·1	43·3	43·8
Std. error	..	..	1·2	1·8	Not significant	1·5
Significant difference ($P = 0·05$)	..	..	3·5	5·3	Not significant	4·3

The fluctuation in yields in different years can be ascribed largely to variations in the number of tappings, according to weather conditions. A significant response is shown to manuring with N, NK, and NPK, but the results for the present are treated with some reserve owing to an unfortunate initial randomization of the treatments, which resulted in several of the lowest-yielding plots being allocated as controls.

So far yields have been recorded at every tapping, but high and significant correlations have been found between the complete results and sample yields taken at random from the records at approximately monthly intervals. It is intended to change to the sampling method of yield-recording in 1942, thus enabling the assistant in charge of the

TABLE 6. *Effect of Fertilizer Treatment on Young Rubber. Mean Girth in Inches per Plant* (*at 3 feet above Union*)

Years since planting	0	N	P	K	NP	NK	PK	NPK	*Compost*	*Significant difference*
2	4·45	4·14	4·41	4·47	4·47	4·55	4·64	4·80	4·68	Not significant
3	7·06	6·84	7·46	7·00	7·90	7·55	8·08*	7·84	8·17*	$P_{0·05} = 0·86$
Increment for year 1940–1	2·61	2·70	3·05	2·53	3·43†	3·00	3·44†	3·04	3·49†	$P_{0·05} = 0·57$ $P_{0·01} = 0·77$

* Significant at 5 per cent. level. † Significant at 1 per cent. level.

experiment to supervise several additional experiments of an improved type which will be laid down on outside estates.

A fertilizer trial with young Rubber in a replanted area was started in 1938. Treatments are 0, N, P, K, NP, NK, PK, NPK, and compost; they are replicated sixfold, and each block is planted with budded stumps of a different clone. Results for the third year are shown in Table 6.

If the results are analysed on a factorial basis (omitting the compost plots) responses are obtained for the 1941 measurements as shown in Table 7.

TABLE 7. *Mean Response to Individual Fertilizers* (*Mean Girth 7·47 in.*)

Sulphate of ammonia	+0·13 in.
Rock phosphate	+0·71 „
Muriate of potash	+0·31 „
Significant difference	P 0·05 = 0·41 in. P 0·01 = 0·55 in.

Arrangements were made for somewhat similar trials (excluding the compost treatment) to be undertaken on some commercial estates. A small significant response to manuring is shown in 3 trials out of 7 which have been continued for 3 years. The mean figures for all the trials give an indication of a small general response to manuring, and a slight superiority of phosphate to other plant-foods. A more comprehensive experiment, involving 27 treatments replicated four times, undertaken on an estate with a limestone soil, has shown no significant response after 3 years.

A comparison between compost and an inorganic fertilizer of corresponding nutrient-content has been in progress for 4 years in a young clearing opened from jungle at Nivitigalakele. In this experiment 38 clone-trial plots were subdivided, each sub-plot being treated with one of the fertilizers. The latest series of measurements showed no appreciable difference in the size of the trees and the girth-increases during the preceding 12 months.

A study was made in a clearing at Nivitigalakele of the effects of adding P, K, and PK in the planting-holes at the time of planting budded stumps. Girth-measurements, made 12 months after planting, showed a significant increase of about 18 per cent. in the P plots.

Several fertilizer trials have been undertaken in seedling nurseries, but no substantial responses have been obtained. In one trial there was a strong indication that an improved percentage of budding successes was obtained with plants that had been manured with nitrogen. Unfortunately the figures could not be examined statistically, owing to the work not having been randomized between the individual budders. In a comparison of nitrogenous fertilizers the best apparent response was with blood-meal and the worst with nitrate of soda.

Generally speaking, the response of young Rubber to manuring, as indicated by the trials in progress, has been distinctly disappointing in relation to the outlay involved. On the other hand, it is encouraging to find that a fair rate of growth has been maintained on replanted land without the application of manures.

The recommendation now made to estates is to apply phosphates only in areas where the general level of growth is satisfactory. For backward areas or backward trees the use of an NPK mixture is advised.

CHEMICAL DEPARTMENT. (Staff: *One Chemist*)

The Chemical Department is concerned with problems relating to latex, the preparation of raw rubber for the market, and the quality of the product. The laboratories are equipped for general chemical work and for carrying out physical tests on latex and on raw unvulcanized rubber. Dartonfield estate factory is provided with modern equipment for the preparation of smoked sheet, crêpe, and preserved latex. An experimental wing of the factory is equipped with small-scale vulcanizing equipment.

In earlier years when less was known about the preparation of rubber, useful work was undertaken on the prevention of defects, such as 'rust', mould, fungal spots, bubbles, arising from the action of micro-organisms on the latex and rubber. Problems relating to smoke-drying of sheet rubber and warm-air drying of crêpe were also investigated. Work now undertaken on the preparation of the normal commercial grades of raw rubber mainly relates to the improvement of factory efficiency, and the relationship between factory methods and the physical properties of the rubber.

A few years ago, in view of local interest in the possibilities of industrial development of the country, the department undertook the task of demonstrating the methods involved in the preparation of various types of commercial vulcanized products. The scope of the work was limited by the equipment available, but a variety of simple products was prepared to illustrate the main manufacturing processes, namely, moulding, extruding, and sheeting.

The attention of the Chemist is now mainly directed to the following subjects:

Preparation of uniform rubber.—A survey has recently been made of the range of variability in the physical properties of rubber prepared on local estates exceeding 1,000 acres, and trials are being undertaken to ascertain the extent to which abnormalities in properties can be corrected by modifying factory procedure. Rubber from monoclonal plantings is to be examined with a view to detecting abnormalities which might be of technological value.

Latex export.—Practical problems relating to the export of preserved latex are being studied. At present latex is not produced on local estates, but the Research Scheme has exported small quantities on a commercial basis for several years in order to study and demonstrate the methods involved. As a war-time measure arrangements have been made to prepare increased quantities of latex for export to India.

The work of the department is carried out in close co-operation with the London Advisory Committee for Rubber Research (Ceylon and Malaya), which undertakes complementary work on the quality of rubber at the Imperial Institute. The Committee in turn maintains close co-operation with users of the product.

SMALL-HOLDINGS DEPARTMENT

The function of the department (formed in 1936) is to advise and assist small-holders, who are defined, for this purpose, as the owners of Rubber lands not exceeding a total area of 30 acres. The work is in charge of the Small-holdings Propaganda Officer, who is a trained Agriculturist, and who has a staff of seven Instructors stationed in the main Rubber-growing areas.

The instructors visit small-holders in their ranges and conduct practical demonstrations of tapping, disease-treatment, soil-conservation measures, bud-grafting, sheet-making, &c. In each range a number of cheap demonstration smoke-houses has been constructed by the Research Scheme, and assistance is given to small-holders in building similar houses on their holdings. A small area has also been replanted with budded Rubber in each range to serve as an example of recommended methods of planting and upkeep. The instructors assist small-holders who undertake replanting by lining the areas for holes and drains, and by supervising other field operations. Reliable planting material is supplied to small-holders at reasonable prices, but the free distribution of material has been avoided except for demonstrational purposes. Competitions are organized annually in each range to encourage the adoption of improved methods.

When it is stated that there are more than 100,000 small-holders in Ceylon it will be clear that the staff of the department is quite inadequate to assist all of them. Nevertheless, valuable assistance is being given to many small-holders who are interested in improving their methods, and a marked improvement in tapping and sheet-making, in particular, has already been effected in some areas.

Acknowledgements

The thanks of the Research Scheme are due to Sir John Russell and the staff of Rothamsted Experimental Station for their valuable assistance in the design of field experiments. Three of the Scheme's officers have received short periods of training in the statistical department at Rothamsted, and requests for advice by correspondence have always met with a cordial response. Sir John visited Dartonfield when passing through Ceylon in 1939, and it is at his suggestion that a record of the work in progress has been compiled.

(*Received December 12, 1941*)

Illustrating the beneficial effects of sulphur-dusting to control fungi of the powdery-mildew class

MANURIAL TRIALS WITH IRRIGATED SULTANA VINES IN THE MURRAY VALLEY, AUSTRALIA

D. V. WALTERS

(*Commonwealth Research Station, Merbein, Victoria, Australia*)

Introduction

THE Murray Valley produces over 90 per cent. of the dried fruits grown in Australia, the quantity of which ranges from 70,000 to nearly 100,000 tons per annum. Sultanas comprise about 60 per cent. of this total, Zante currants range from 15 to 20 per cent., lexias (dried Gordo Blanco) are usually about 10 per cent., and dried tree-fruits are usually less than 10 per cent. Of approximately 70,000 acres under irrigation for horticultural purposes along the Murray River from Swan Hill to Waikerie (300 miles), 57,000 acres are under vines and 60 per cent. of these are sultanas. There are six major settlements ranging from 7,000 to 11,000 acres, and a number of smaller settlements, in this region.

The climate of the Murray Valley is sub-continental with a low and unreliable rainfall and high average temperature and evaporation. The climate is admirably suited to the production and drying of vine fruits, the spring being clear and warm, and the summer and early autumn hot and dry. A mean of less than five frosts per month occurs during the winter, with a chance of a damaging frost in the susceptible portions of the settlements one year in three. The rainfall ranges from 13 in. per annum at Swan Hill to about 10 in. per annum from Mildura to Waikerie.

The pioneer settlement of Mildura was started in 1887 by George and William Chaffey, Californian irrigation engineers, and by 1891 a small tonnage of dried fruit was produced. Early plantings were mixed, comprising vine, citrus, and deciduous fruits, and large areas went out of production during the severe financial reverses of the '90's. When reorganization began, experience showed that the soil and climate were suited to the vine, so that later settlements immediately before and just after the 1914–18 war were started as predominantly vine-settlements.

In the early days of the Murray Valley settlements many of the growers had wheat-farming experience, and consequently superphosphate was the chief fertilizer used. Growth of winter cover-crops did not become general until about 1930, when additional irrigations were provided for this purpose. Blood-and-bone fertilizers have been popular of recent years, and sulphate of ammonia is increasing in popularity and because of its relative cheapness is the only inorganic fertilizer used, excepting superphosphate, with the cover-crops. Potash in the form of the sulphate or chloride has been used, but has not become popular. Gypsum from local deposits has been used over many years as a soil amendment on the heavy soils, with undoubted benefits. Other fertilizers or soil amendments have of course been tried, but have not been of any commercial importance.

The sultana manurial trials carried out by the Commonwealth

Research Station, Merbein, have been initiated in nearly every instance by growers' organizations and research committees, who have provided the necessary funds. All the trials (except one at the Station) have been carried out on growers' properties, and trials have been conducted in every major settlement on a number of major soil types.

Cultural Methods

The sultana vines of the Murray Valley are propagated by cuttings on their own roots. As Phylloxera has not appeared, resistant stocks have been unnecessary. The sultanas are usually planted in rows 11 or 12 ft. apart, and spaced at 8 or 9 ft. intervals within the rows. The trellis consists of 6 ft. posts, 4 ft. 6 in. out of the ground, spaced about 30 ft. apart and carrying two or more wires in the vertical plane. The permanent wood is established on the lower one of two, or on the lower two of three, wires at about 30–40 in. from the ground. Newer forms of trellis (T-trellis) allow of the establishment of the fruit-bearing wood at about 40 in. from the ground on two wires about a foot apart in the horizontal plane. The topmost or foliage wire supports the summer growth and keeps it out of the way of cultivation implements.

The sultana differs from most horticultural plants in that the yield bears a close relationship to the number and size of the fruit-buds laid down on the annual wood. Not all the buds are fruitful; and as the base buds are usually unfruitful, spur-pruning would result in a small crop. The method of pruning is therefore to select from convenient positions on the permanent framework of the vine a suitable number of canes (or rods) arising from two-year-old wood. The rest of the annual wood and the two-year-old wood which bore fruit in the previous year are then removed and the canes twisted on to the trellis wires. The prunings are buried in deep trenches (12 in. to 18 in.) or raked out and burnt. The length of rows in the more recent settlements averages about 6 chains, the greater length of up to 12 chains in older settlements being found unsatisfactory for irrigation. The multiple-furrow system is generally adopted to overcome the prolonged soakage resulting from two-furrow irrigation. The system of semi-flooding is practised on some of the heavier soils. Cultivation methods include the growth of a green-manure crop, which is sown in the early autumn and turned under in early spring. The tick or horse bean (*Vicia faba*) is the most popular green-manure crop, but the field pea (*Pisum sativum*) and the vetch or tares (*Vicia sativa* and *V. villosa*) are also used. Cereals (wheat, oats, barley, and rye) are sometimes used on light sandy soils. A deep ploughing is usually given before the vines sprout; and after each irrigation the soil is cultivated with a rigid tine, spring tooth or disk cultivator, for weed-control and for preservation of soil tilth. Special single-horse implements are used to control weed-growth under the rows of vines. There are usually four irrigations from sprouting to harvest; and two in the autumn to grow the green-manure crop and maintain vine-health for satisfactory maturation of the canes. A ploughing in summer is common and gives protection from the effects of summer heat-waves by forcing the growth of feeding-

roots below the cultivated zone, to the region where temperatures are lower.

Soils

The soils of the Murray Valley irrigation settlements have been described by the C.S.I.R. Division of Soils [1] and comprise two main groups, the river-flat and the mallee types. The majority of the soils of the river-flat group are heavy in texture and alkaline in reaction, but are usually relatively low in lime. They comprise only a small proportion of the horticultural areas. The mallee soils are light-textured members of the great group of grey and brown soils with special characteristics which appear to make them peculiarly Australian [2]. They are somewhat solonized and highly calcareous. Their special characteristics appear to be determined by the accession of cyclic salts and by a rainfall with low leaching powers. Under a more arid climate in the past they have been built up into sandhills which are now fixed by vegetation and on which the present mature profile has developed. In general they are of a uniformly pinkish light-brown colour, and are usually alkaline with a pH range of 7·5 to 9·5. They invariably contain calcium carbonate in the subsoil, often as rubble or in sheets as well as in a very fine state of subdivision. In the Murray Valley the mallee soils carried a number of native vegetation associations of mallee scrub (*Eucalyptus* spp.), Murray pine (*Callitris glauca*), belar (*Casurina lepidophloia*), blue bushes (*Kochia* spp.), and saltbushes (*Atriplex* spp.). The parallel sand-hills are light in texture with heavier soils between them. The texture and salt-content are the cause of salt and water-table troubles arising under irrigation. Most horticultural settlements have been served with underground-pipe main drains which dispose of the drainage waters collected by agricultural drains within each holding. The drainage schemes are providing a means of successfully overcoming salt and seepage troubles.

Analyses [3] have shown that the Murray Valley soils are deficient in phosphates, nitrogen, and organic matter, but are relatively well supplied with potash. Whilst total nitrogen is practically constant throughout the year, the nitrate-nitrogen content rises from a minimum in early spring to a maximum about December. This occurs on both fallowed and green-manured land, and is related to rising temperatures. It appears that the vine absorbs most of its nitrogen in the form of nitrate. Losses of nitrates by leaching into the drainage system, although appreciable, probably do not exceed 10 lb. of nitrogen per acre per annum. There does not appear to be any permanent improvement in the nitrogen status of the soil even after 10 or 20 years of intense green manuring or other fertilizer practice. It is thus necessary to add the seasonal requirements of nitrogen each year.

Experimental Procedure

1. *Plot-size.*—In the manurial trials discussed in this paper the size of the artificially manured plot was determined after consideration of the variability of vine yields and the rooting habits of the vine. Despite the inherent similarity of clonally reproduced sultana vines growing on

their own roots, the coefficient of variability (standard deviation as a percentage of the mean) of the yield of dried fruit from single vines ranges from 25 to 35 per cent. Variability trials involving up to 400 vines suggested that the optimum plot-size contained 6–9 vines, as 2 rows of 3, 2 rows of 4, or 3 rows of 3 vines. Such plots showed a coefficient of variability of about 8 to 12 per cent. and 9 replicates would be expected to show as significant differences between means of 10 per cent. It will be noted that these figures agree closely with those of Strickland [4], who measured the yields of fresh fruit on 200 vines of a wine variety (Shiraz) under non-irrigated conditions in the upper Murray Valley.

The rooting habits of the sultana have been described by Barnard [5] as shallow and widespreading, with considerable overlap of the root-systems of adjacent vines. The main roots average approximately 10 ft. in length, so that few roots pass the adjacent vines, and these are rarely more than 15 ft. in length. Present cultivation methods include deep ploughing and usually trenching or subsoiling, which restricts root-extension across the rows, but not along the rows.

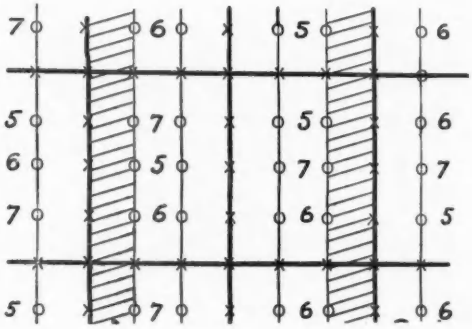
In most of the trials discussed here 6 vine plots were used, with 2 rows of 3 vines each, and surrounded by a single guard row. This gave the minimum practicable plot, and has proved satisfactory. The area of the plot to which the fertilizer is applied is designed to include the roots of the measured vines. The bounds of the plot were marked by erecting a bamboo pole at the guard-vine at each corner, and the treatment was shown by a sign erected at a convenient trellis post within the plot.

Application of the artificial fertilizer was made by the method in most common use amongst growers, namely by broadcasting over the whole plot. The standard method of growing green manure is to sow the tick beans with heavy dressings of superphosphate (at the rate of 4–8 cwt. per acre) in every second row in one year, and in the alternate rows in the following year. In some of the trials the green manure was sown as a strip in one of the inter-row spaces between one of the measured rows and the guard row. This made the green manure a split-plot treatment. On sites subject to salt or seepage, growth of green manure continuously in one row, without irrigation of the other two rows in autumn, introduced the secondary effect of salt-damage in the row not green-manured. Where green manure was applied as a main effect, it was applied in alternate years in every second row of the plot, as described for the standard method, or in every row of the plot each year. In such trials the drill was lifted out at the boundary of the plot, and left out while traversing control plots. The plot boundaries were then trimmed by hoeing out unwanted plants after germination.

Viticultural studies have shown that increased growth is associated with increased yields. Therefore different levels of pruning have been included on most of the trials to provide that increased growth due to treatment may reflect as increased yield. The bearing unit of the sultana is the cane, and levels of pruning were defined in terms of canes per plot.

2. *Design of the field trials.*—Several designs have been used, only two

being duplicated. The two earliest trials were 5×5 Latin squares, with 6 measured vines per plot, in 2 rows of 3, surrounded by a single row of guard-vines. These were expected to demonstrate significant differences between means of treatments of 15 per cent. As these trials proved more variable than expected and suffered frost damage, they were not continued after 3 years. They indicated that manurial treatments gave increases in yields over the unmanured controls of no more than 30 per cent. and more often of the order of 10 per cent. Later trials were laid out with this fact in mind and have shown that it is difficult to increase



the yield of the vine by any manurial or cultural treatment (given adequate irrigation) by more than 15 or 20 per cent.

An 8×8 Latin-square design was applied on each of two sites, involving presence and absence of N, P, and K with 8 replicates, using sulphate of ammonia, superphosphate, and sulphate of potash, each at the rate of 4 cwt. per acre. Later, at the request of the growers sponsoring the trials, green manure was added as a half-strip to each column of the Latin square; and three levels of pruning (5, 6, and 7 canes) were added to pairs of vines within each 6-vine plot. The plot detail is shown in the sketch above.

The thin vertical lines represent the vine-trellis, the treated vines being marked with a circle and the guard-vines with a cross. The boundaries of the artificial-fertilizer plots are shown by the thick black lines. The numbers refer to the number of canes left at pruning, on the treated vines to left and right of the numbers. The cross-hatched area represents the space between vine-rows to which green manure is applied. This gave 6 treatments on the 6 vines of the plot (all combinations of green manuring and levels of pruning) and with the 8 fertilizer treatments made 48 in all, replicated 8 times and covering about 2 acres.

It has been possible to demonstrate significant differences between means of the main effects as low as 5 per cent. (for $P = 0{\cdot}01$) on one of these trials, on very flat and uniform soil. The analysis of variance of this trial is rather involved and time-consuming, and with subsequent experience a more easily handled trial could be designed to answer the

same questions. These two trials have been carried on for 8 and 6 years respectively, and are being continued. The form of analysis of variance is as follows:

Analysis of Variance

Due to		*Degrees of freedom*
Rows		7
Columns		7
Artificial manures:	N	1
	P	1
	K	1
	NP	1
	NK	1
	PK	1
	NPK	1
Error for rows, columns and 'artificials'		42
Pruning		2
Interaction, pruning and 'artificials'		14
Error for pruning and for interaction, pruning and 'artificials'		112
Green manure		1
Error for green manure		7
Interaction, 'artificials' and green manure		7
Error for interaction, 'artificials' and green manure		49
Interaction, pruning and green manure		2
Interaction, 'artificials', pruning and green manure		14
Error for interaction, pruning and green manure; and for interaction, 'artificials', pruning and green manure		112
Total		383

A small trial covering nearly 1 acre and designed to test the relative merits of green manure (standard practice of alternate rows) and sulphate of ammonia (2 cwt. per acre) has completed its third year. The four treatments (N, G, NG, O) are replicated 4 times, and each plot is split into high and low levels of pruning (7, and 9 or more, canes). The split plot contains 4 vines, and each manured plot of 8 vines is surrounded by a single guard-row. This design will demonstrate significant differences between means of the main effects of the order of 10 per cent.

As blood-and-bone fertilizers are the most popular form of artificial nitrogen, a request was made that a trial be started to compare this organic manure with the inorganic sources of phosphate and nitrogen (superphosphate and sulphate of ammonia). It was possible to obtain dried blood with 12 per cent. N relatively free from phosphates, and ground-bone flour with 30 per cent. P_2O_5 relatively free from nitrogen. The trial includes 3 treatments involving nitrogen, 3 involving phosphates, and 2 involving green manure. These 18 treatments are replicated 4 times, each replicate being arranged in 3 blocks of 6 plots each so that two of the higher-order interactions are confounded with block totals. Each plot of 6 vines is surrounded by a single guard-row, and split at random into high and low levels of pruning (7, and 9 or more, canes per vine). The trial covers about 2 acres, and has completed its third year. The plan of the trial is as follows:

OPO	OO*g*	N*p*O	*n*O*g*	NOO	O*p*O	O*pg*	NPO	NO*g*	1st Replicate
npg	*n*OO	NP*g*	*n*PO	N*pg*	OP*g*	OOO	*n*P*g*	*np*O	
OOO	OP*g*	*n*O*g*	*npg*	NOO	NP*g*	N*p*O	*n*P*g*	*n*OO	2nd Replicate
*np*O	N*pg*	NPO	O*p*O	*n*PO	OO*g*	OPO	NO*g*	O*pg*	
OOO	*npg*	*n*PO	OPO	NOO	*n*O*g*	*n*OO	O*p*O	NPO	3rd Replicate
NO*g*	OP*g*	N*p*O	*np*O	O*pg*	NP*g*	*n*P*g*	N*pg*	OO*g*	
NPO	*npg*	O*p*O	*n*PO	OOO	*n*O*g*	NOO	OO*g*	N*pg*	4th Replicate
OP*g*	*n*OO	NO*g*	NP*g*	N*p*O	O*pg*	*np*O	OPO	*n*P*g*	

The treatments are:

Nitrogen	O	= no nitrogen
	N	= 5¼ cwt. per acre dried blood
	n	= 3 cwt. per acre sulphate of ammonia
Phosphates	O	= no phosphates
	P	= 3·66 cwt. per acre bone-dust
	p	= 5 cwt. per acre superphosphate
Green manure	O	= absence
	g	= presence

The treatments N and *n* contain equivalent amounts of nitrogen, and the treatments P and *p* contain equivalent amounts of phosphorus.

In contrast to the highly organized designs noted above, all of which were situated in Victoria, a survey of the response to 4 cwt. per acre of sulphate of ammonia was carried out over 3 seasons on 12 sites, covering 3 major settlements in South Australia. The plots contained 16 vines each, with 4 plots per site (2 treated and 2 controls). Information obtained was of the same order as that on the other trials.

3. *Factors measured, and experimental technique.*—Experience has shown that the value of a record of yield data from a manurial trial is enhanced if the effects of the various treatments on the components of yield are known also. Various factors have been measured for this reason; other factors have been measured with a view to determining the relation of vegetative growth to yield of fruit; and others again are of use in forecasting yields for trade purposes.

During the winter the number of canes that are available for use as fruiting wood is recorded, and the levels of pruning fixed according to the canes available. The vines are pruned and the one-year-old and two-year-old wood cut into convenient lengths, placed on a small canvas sheet, and weighed by spring-balance held at arms' length. If there is more than 10 lb. of prunings, it is more convenient to fix the scales to a pole supported on the shoulders of two men. A record is made of the number of canes and buds left at pruning, the latter being recorded on a mechanical counting device to relieve tedium.

The artificial fertilizers are applied in early spring, the appropriate amount of each manure per plot being weighed into buckets and spread by hand, checking against the plot label. Later in the spring the

number of buds which sprout, and the number of bunches appearing, are recorded by the counting-device. The percentage of buds sprouted and the number of bunches are both estimates of the coming crop, and data from the manurial trials are used by the industry in preparation for the disposal of the crop.

At harvest the number of bunches picked is recorded in the field, the two rows comprising one plot being picked simultaneously. The buckets of fruit are weighed, using a spring-balance suspended from a light wooden tripod. Each bucket of fruit is labelled, giving the location of the plot and the number of buckets from the plot. At the drying-ground the fruit from a given plot is assembled, dipped in the usual manner, and spread together on the drying-rack. For the purposes of these experiments specially designed drying-racks have been constructed consisting of 14 tiers of 2 in. wire netting, 5 ft. wide, spaced 6 in. one above the other, and roofed with galvanized corrugated iron. A hessian (burlap) sheet is spread on alternate tiers to catch berries that fall during spreading of the fruit. Fruit from different plots is separated on the rack by a space of 6–12 in. and labelled. A gang of 12 men for 2 9-hour days is required to harvest one of the larger trials. When the fruit is dry, in about 10–20 days, according to weather conditions, a gang of 6 men can remove and weigh the various lots of dried fruit in about 1 day. The replicates from each treatment are bulked and samples taken for determination of quality and for analysis on selected trials of moisture, sugar, potash, phosphate, nitrogen, and acid-content.

In the autumn a survey of the appearance of the foliage is made just before leaf-fall, and after leaf-fall a check count is made of the shoots that have persisted or sprouted late during the past season. Green manure is drilled in during early autumn, under supervision and checking from a plan of the trial.

The ultimate yield measurement, i.e. the weight of dried fruit, is made up of the four components: number of bunches; number of berries on the bunch; size of berries; sugar-content of berries. In practice it is not expedient or desirable to measure each component of yield separately. The number of bunches is an important consideration and is readily obtained. The sugar-content of the berries is an indicator of the stage of maturation at harvest, and is obtained for this reason. It may be determined by floating a Baumé hydrometer in the expressed juice of the fruit. However, difficulties in obtaining representative samples and of carrying out the Baumé determination during the rush of harvesting have necessitated a different approach. There is a very high negative correlation ($r = -0{\cdot}95$) between the drying ratio (ratio of fresh to dried weight of fruit) and the Baumé reading, and a special technique has been developed in drying small lots of fruit. The drying ratio is then used to express the stage of maturation. Berry-size is not of great commercial importance and is not as a rule estimated. The determination of the number of berries on the bunch is too tedious to be considered.

The moisture-content of dried fruit on delivery from the grower ranges from 15 to 18 per cent., and fruit from one trial has an even

smaller range, so that variation in moisture-content is a negligible consideration.

For statistical analysis of the data forms are prepared on a duplicator in the form of a plan of the trial, showing each treatment and allowing a space for insertion of the yield measurements. In addition to the factors mentioned, analyses are made of ratios, such as the drying ratio, the sprouting percentage, and ratio of bunches to buds.

Results

1. *Nitrogen.*—The outstanding result of all the trials is the fact that nitrogen was the only fertilizer element to give substantial and continued increases in yield of dried fruit. The results from one experiment may be quoted to illustrate the type of data obtained.

From this trial the analysis of variance of which has been shown previously, the following yields of dried fruit in cwt. per acre were obtained in the three seasons:

Treatment	*1938*		*1939*		*1940*	
	Present	*Absent*	*Present*	*Absent*	*Present*	*Absent*
Sulphate of ammonia .	41·5	35·7**	35·2	32·4**	39·2	36·7**
Green manure . .	39·5	37·7	34·5	33·1*	39·1	36·8*
Interaction N × G .	37·3	40·0**	34·2	33·5	37·3	38·6
Superphosphate . .	39·0	38·2	33·6	34·0	37·8	38·1
Sulphate of potash .	38·6	38·6	34·3	33·4	38·3	37·6

** = significant $P = 0{\cdot}01$, * = $P = 0{\cdot}05$

In addition to the significant effects shown, there was in 1938 a significant z test for levels of pruning, otherwise there were no other significant results.

Sulphate of ammonia, the most readily available nitrogenous fertilizer tried, has shown the largest responses, of the order of 8 to 18 per cent. increase compared with absence of nitrogen. Dried blood containing an equivalent quantity of nitrogen has shown almost the same result. Green manure has not shown consistent results, but appears to improve in its effect after several years. It has been shown that a good green-manure crop as usually grown in alternate rows provides about the equivalent of the nitrogen in 1 cwt. per acre of sulphate of ammonia. Yields of green manure are naturally very variable from year to year, according to the nature of the season, being lowest after a dry winter.

The increase in yield by the use of nitrogenous fertilizers is brought about by an increase in the number and weight of bunches, without any significant reduction in the stage of maturation at picking. Quality in sultanas is measured in the trade term 'Crown grade', ranging from 5-Crown for the best to 1-Crown and some lower grades. Grading is based on size of berry, lightness of colour, uniformity, and general appearance. Colour is the dominant factor, and quality is determined to a great extent by weather conditions during drying. Nitrogenous fertilizers depress quality significantly but only to a slight extent, of the

order of one-quarter or less of a Crown grade in a year when good quality is obtained (4-Crown); when it is not possible to obtain better than 3-Crown, no depression of quality is noticeable. No effect of any treatment has been noted on the keeping-quality of the fruit when it is stored up to 12 months.

Application of sulphate of ammonia is reflected in a greatly increased nitrogen-content of the dried fruit compared with fruit from control plots (from 0·50 to 0·70 per cent. approximately, on a dry-weight basis), with a tendency for a related decrease in sugar-content from 82 to 81 per cent. approximately. Green manure also increases the nitrogen-content of the fruit, to a very small although significant extent. Sulphate of ammonia increases the acidity of the fruit from 2·4 to 2·7 per cent. approximately (as tartaric acid) with a related increase in the potash-content from 1·2 to 1·4 per cent. approximately, the acid of grapes being potassium hydrogen tartrate. It also depresses significantly the phosphorus-content from 0·15 to 0·14 per cent. approximately. No analyses have been made of fruit from plots treated with blood-and-bone fertilizers.

When nitrogenous fertilizers are applied no effects are noted at the harvest following the first application. After the second application an increase in yield usually results. It appears, therefore, that nitrogen has little effect on the current crop, but it increases bud-fertility and vegetative vigour to the extent that an improvement in the following crop results. Analyses of the fruit bear out this statement.

2. *Phosphates.*—The application of superphosphate is reflected only in the amount of phosphorus in the fruit, causing an increase from 0·140 to 0·155 per cent. approximately. No other measurements have been affected in any way by the use of either superphosphate or bone-flour. An average crop removes the equivalent of a little over ½ cwt. of superphosphate per annum, an amount readily made up from that supplied to the green crop.

3. *Potash.*—Sulphate of potash has likewise had no effect on any measurements made, although the appearance of vines treated with potash alone is somewhat better than that of vines treated with superphosphate alone. Since an average crop removes in the fruit and the prunings the equivalent of about 1 cwt. per acre of sulphate of potash, it might be expected that a deficiency of potash may arise in time. The vines under trial are about 20 years old.

4. *Levels of pruning.*—The variation in levels of pruning that have been applied has given significant differences in yield in most years on all trials, ranging from 7 to 12 per cent. increase in favour of the greater number of canes. Where three levels of pruning have been applied, the lowest level has reduced yield, and the other two levels have not differed significantly from each other. On single-vine plots it is necessary to make the highest level of pruning about equal to the average number of available canes, otherwise it would not be possible to wrap down the required number of canes on all vines. With plots of three or more vines it is possible to make the total number of canes on the plot equal to that required by allowing more canes on some vines to make up for deficien-

cies in other vines. The highest number of canes used has been less than 10, whereas some growers average 12 per vine. On trials designed to examine only the effect of variation of number of canes, the maximum number available usually gives no more dried fruit than a moderate number, although there is a tendency for increased fresh fruit and slower maturation.

5. *Statistical significance.*—It is interesting to note that there have not emerged from the trials any significant interactions of treatments. When both green manure and sulphate of ammonia give increases in yield in a trial, their effect in combination tends to be additive. Thus in one trial N and G each gave an increase of 10 per cent. over the controls, whilst NG gave an increase of 15 per cent.

In the above discussion all differences of means that have been noted as significant have a probability of 1 per cent. or $P = 0{\cdot}01$. It is noteworthy that where, as occasionally happens, a difference between means with a probability of 5 per cent. occurs, this treatment does not as a rule repeat its effect in subsequent years. In other words, one can place reliance on a difference with a probability of 1 per cent. but not on one of 5 per cent.

6. *Compensating effects.*—The vine is a perennial plant, and its product is chiefly sugar. It is subject to the cumulative effects of cultural treatments, it reacts to extremes in yield by alternating to the other extreme, and is capable of considerable compensating effect in respect to yield. Not enough data are yet available to define the extent of these three effects, although examples are well defined in several instances. Thus continued low level of pruning (hard cutting-back) may give in time reduced vigour. Seasonal conditions may give a light or heavy crop, and the alternative yield is experienced in the following season. Compensation for a low potential crop is expressed in bigger bunches containing more sugar; for a high potential crop in smaller, less mature bunches. Alternations of yield do not show defined peaks and depressions, and it seems possible that in one plot of vines there may be several systems of alternation proceeding on different vines at the one time. The net result of all the effects considered is relatively gentle fluctuations in total yield from a group of vines over a period of years, which is some explanation of the difficulty met in obtaining increases in vine-yield by treatment amounting to more than a very small percentage. It is suggested that a minimum period of 7 years is necessary for the conduct of a manurial trial, and that continued treatment for much longer periods may give valuable information.

Summary

The sultana comprises 60 per cent. of all dried fruits produced in Australia, and is grown under irrigation in separate settlements along 300 miles of the Murray River. Manurial trials present special problems owing to the perennial nature of the vine, the special character of the pruning, and the small responses obtained to any special treatment. Owing to the value of the crop, however, even small responses may be of commercial importance.

The optimum plot-size contains 6 vines in 2 rows of 3, surrounded by a single guard-row. Levels of pruning may be applied as a split-plot treatment.

The designs of the trials are described briefly.

Various factors are measured in order to define yield differences, to determine the relation of vegetative growth to yield, and for use in forecasting yields for trade purposes. The factors measured, and the technique developed to measure them, are described.

Nitrogen is the only fertilizer element to give consistent increases in yield, which are of the order of 8–18 per cent. Sulphate of ammonia gives best results, but dried blood and winter green-crops of tick beans (*Vicia faba*) are also satisfactory. Phosphates and potash have had no effect on vine-yield. High number of canes has been more satisfactory than the lowest level of pruning.

An explanation is attempted of the small changes in vine-yield experienced under even the most favourable treatments.

Acknowledgements

It is desired to acknowledge the co-operation of Messrs. R. C. Polkinghorne, Woorinen; N. Eddie, Coomealla; and J. L. Smith, Red Cliffs, on whose properties the largest trials were conducted, as well as a number of other growers whose properties were used. The author is indebted to Mrs. Calvert (*née* Miss F. E. Allen) who assisted with the design of the trials, and to the members of the staff of this Station for continued assistance.

REFERENCES

1. C.S.I.R. Bulletins, Nos. 42, 45, 56, 62, 73, 86, 107, 123, 133, 137. (Soil Surveys of Murray Valley Settlements.)
2. J. A. Prescott, The Soils of Australia in relation to Vegetation and Climate. C.S.I.R., 1931, Bull. No. 52.
3. J. A. Prescott and C. S. Piper, The Soils of the South Australian Mallee. Trans. Roy. Soc. S. Aus. 1932, **56**, 118–47.
4. A. G. Strickland, A Vine Uniformity Trial. J. Agric. Vic., 1932, **30**, 584–93.
5. C. Barnard, The Root-system of the Sultana. Jour. C.S.I.R., 1932, **4**, 88–93.

(*Received December 30, 1941*)

THE ENSILAGE OF CITRUS FRUIT PULP

A BONDI.

(*Agricultural Research Station, Rehovot, Palestine*)

EXPERIMENTS carried out in California [1, 2] and in Palestine [3] have shown that fresh citrus pulp, discarded as waste by the fruit-juice industry, is a suitable food for dairy cows. Fresh orange pulp, however, tends to spoil rapidly and become unpalatable after a few days' standing. It was deemed important, in view of this and of the brevity of the citrus season (December–April), and the shortage of succulent feed in most parts of Palestine particularly during the summer, to investigate the possibility of preserving the orange pulp by ensilage. This method of preservation does not entail the considerable capital and current expenditure necessary for the operation of the artificial drying-method of fruit-pulp preservation common in California and Texas [1, 2].

Ensilage experiments on orange pulp were repeatedly carried out by us during 1935–8, in barrels to begin with and later in a large cement tower. Both orange- and grape-fruit pulp have been investigated.

Material.—The orange-pulp material ensiled was kindly provided by the Jaf-Ora Co., Rehovot. In the mechanical process used in this factory the peel of each fruit is divided into two equal pieces to which a considerable amount of 'meat' pulp clings. Essential oils are removed from this material by mechanical means. The grape-fruit pulp ensiled was not previously freed of essential oils; there are less essential oils in grape-fruit than in oranges.

Ensilage Experiments with Barrels

Experiments were carried out in order to find the conditions most suitable for ensilage of the pulp in barrels. Each barrel contained about 250–300 kg. of pulp. To prevent air from entering the barrels, the material was pressed down as tightly as possible, covered with layers of paper and straw, and finally with earth to the top of the barrel. In some experiments, orange waste finely minced was ensiled without addition of any preservative. When the barrels were opened after 8 months, the citrus waste appeared to be well preserved: the tissue was somewhat softened, the odour was pleasant and not acrid. The changes in the chemical composition of the material during ensilage are of interest (Table 1). N-free extract and sugar showed a decline. The drop in N-free extract must have increased the percentage figures found for other constituents, such as protein, fat, crude fibre, and ash. The deficit of sugar was partly accounted for as formed lactic and acetic acids. The lactic acid is desirable and its nutrient value approximates to that of sugar [4]. Butyric acid was absent from the orange pulp before ensilage. Grape-fruit pulp silage contained the acid in only very small amounts, which are not injurious. The silage yielded negative tests for citric acid.[1] It is noteworthy that all the citric acid which had

[1] According to the pentabromacetone reaction and to the spot test of Feigl (Forma-

TABLE 1. *Composition and Properties of Citrus-Pulp Silage (Barrel Silo Experiments)*

Material	*Mincing*	*Date of sampling*	*Storage time. Days*	*Water %*	*As percentages of dry matter*														*pH*
					Crude protein	*Fat*	*Ash*	*Crude fibre*	*N-free extract*	*Monoses*	*Saccharose*	*Total sugar*	*Pectin*	*Acetic acid*		*Butyric acid*		*Lactic acid. Free*	
														Free	*Bound*	*Free*	*Bound*		
Orange pulp:																			
Starting material	..	9.3.36	..	81·19	7·03	1·49	3·78	9·02	78·67	29·7	7·7	37·4	15·4	..	..	..	..	..	4·0
Silage	+	9.11.36	244	81·86	7·40	2·13	4·28	10·69	75·50	18·0	4·5	22·5	14·9	1·05	0·30	0	0	6·39	3·6
,,	−	9.11.36	244	82·54	7·94	2·28	4·74	12·06	72·98	17·0	0	17·0	13·3	1·89	0·97	0·86	0·34	4·98	3·4
Grape-fruit pulp:																			
Starting material	..	9.3.36	..	82·13	6·95	1·84	3·86	10·52	76·83	29·2	9·6	38·8	..	..	..	..	..	..	3·7
Silage	+	24.11.36	259	81·80	7·81	2·44	4·37	13·67	71·71	19·7	4·8	24·5	..	1·32	0·16	0·38	0·05	8·30	3·5

TABLE 2. *Composition and Properties of Orange-Pulp Silage (Cement Tower Experiment)*

Material	*Date of sampling*	*Storage time. Days*	*Layer from surface cm.*	*Water %*	*As percentages of dry matter*												*pH*
					Crude protein	*Fat*	*Ash*	*Crude fibre*	*N-free extract*	*Monoses*	*Saccharose*	*Total sugar*	*Acetic acid*		*Butyric acid*		*Lactic acid*[1]		
													Free	*Bound*	*Free*	*Bound*	*Free*	*Bound*	
Starting material	23.3.38	..	..	82·50	7·11	0·87	4·37	12·72	74·92	31·2	18·4	49·6	..[2]	..	..	..	..	..	3·9
Silage	23.8.38	155	30	84·00	7·75	1·88	4·85	17·06	68·45	10·9	1·6	12·5	3·69	0·69	0	0	10·25	10·35	3·1
,,	27.8.38	159	70	85·06	..	..	..	..	..	9·7	1·7	11·4	3·68	1·00	0	0	10·70	17·35	3·1
,,	16.9.38	179	100	83·40	..	..	..	..	..	10·4	1·0	11·4	3·84	0·75	0	0	10·54	7·19	3·1
,,	21.9.38	184	150	85·57	..	..	..	..	..	12·2	2·8	15·0	3·81	1·04	0	0	8·87	7·90	3·3
,,	2.10.38	195	190	84·13	7·44	1·93	4·74	16·20	69·69	10·3	1·9	12·2	4·03	0·95	0	0	10·71	3·46	3·15
Average				84·83	7·60	1·90	4·80	16·63	69·07	10·7	1·8	12·5	3·81	0·89	0	0	10·21	9·25	..

[1] Determined by O. Flieg's method (Bied. Zentrbl. Tierern., 1937, **9**, 178).

been contained in the orange waste, particularly the fruit pulp, disappeared during ensilage. Free alcohol was of irregular occurrence, and when formed was found in concentrations (< 0·2 per cent.) that are not injurious [4]. The pH value decreased during ensilage, because of acid formation (Table 1). The amount of pectin declined but slightly during ensilage.[1]

Samples of ensiled pulp, kindly examined by Mr. Babad, were found to be free of spore-forming rods. The organisms present included *Torula* yeast, *Streptococci*, and *Lactobacilli*. In no case was mould found in the interior of the ensiled mass. Cows, calves, and sheep consumed the ensiled citrus pulp readily.

Addition of inorganic acids to ensure the success of the silage appears from the results of our experiments to be quite superfluous. In experiments in which the material was treated with 2N. acid (a mixture of hydrochloric and sulphuric acid; 20 l. to 300 kg. material), according to Virtanen [5], the same results were obtained as in experiments without addition of conservants. Addition of 3N. acid enhanced the cleavage of sugars and softened the material.

Since the mincing of the material leads to increased cost, the effect of mincing on the success of pulp silage was tested in a separate experiment. The analytical data given in Table 1 show clearly that silage of unminced pulp is inferior to silage obtained from minced material, because the unminced material cannot be packed closely enough to ensure complete elimination of air. For the large-scale experiments, described below, only minced material was used.

Ensilage Experiment in a Cement Silo Tower

The large-scale silage experiment was carried out in a round silo tower made of cement, using 10 tons of orange pulp. The diameter of the tower was 2·5 m. and the height 3 m., of which 0·5 m. was underground. The pulp material was machine-sliced to a thickness of about 0·5 cm., and trampled into the container as closely as possible. The packed pulp was covered with tar paper, which was overlaid with straw and a 60 cm. layer of earth. Packing and sealing operations took about two days. In external appearance, the microflora and the chemical composition of the material from the tower silo proved similar to those obtained in the small-scale experiments (Table 2). Only the pH value, however, was found to have dropped more markedly than in the small-scale silos; the loss of sugar was larger and greater quantities of acetic and lactic acids were consequently observed. The quantity of acids formed in the upper layers was greater than in the bottom layers of the silo. The material was entirely free from butyric acid. The feeding-value of orange-pulp silage was determined as described in the following paper.

tion of Citracinic acid; F. Feigl, *Qualitative Analyse mit Hilfe von Tuepfelreaktionen*, 2nd ed., 1935, p. 415).

[1] The methoxyl contents of pectins prepared from fresh and ensiled orange pulp differed only slightly (9·5 and 7·9 per cent. respectively). It may be concluded that the quality of pectin was not influenced by ensilage.

Summary

Experiments were carried out to test the possibility of preserving citrus pulp by ensiling it. Ensiling of minced citrus pulp is readily possible without addition of acid conservants. After 8 months storage, a palatable silage was obtained that contained appreciable quantities of lactic acid, but was entirely or nearly free from butyric acid.

REFERENCES

1. S. W. MEAD AND H. R. GUILBERT, The Digestibility of certain Fruit By-products as determined for Ruminants. I. Dried Orange Pulp and Raisin Pulp. Univ. California, Agric. Expt. Stat., Berkeley, 1926, Bull. No. 409.
2. W. M. MEAL, R. B. BECKER, and P. D. ARNOLD, The Feeding-value and Nutritive Properties of Citrus By-products. Univ. Florida, Gainesville Agric. Expt. Stat., 1935, Bull. No. 275.
3. R. VOLCANI, not yet published.
4. E. CRASEMANN, Mitt. Lebensmitteluntersuch. u. Hygiene (Bern), 1928, **19**, 371.
5. G. WIEGNER, Heubereitung und Silage, Zürich, 1934.

(*Received December 4, 1941*)

THE DIGESTIBILITY OF CITRUS FEEDS

A. BONDI AND H. MEYER
(*Agricultural Research Station, Rehovot, Palestine*)

THE feeding-value of orange-pulp silage and of orange culls has been determined in digestibility experiments with sheep. The citrus silage was prepared as described in the preceding paper. It seemed important to obtain data on the feeding-value of orange culls, as these are now commonly fed to cows all over Palestine. During the citrus-export crisis even quality fruit has been used on a large scale as a live-stock feed.

Digestibility of Orange-Pulp Silage

Two experiments were carried out, each with 3 sheep. The experimental period lasted 10 days; details of the procedure used have been described elsewhere [1]. In the first experiment material was fed to the sheep from the upper layers of a silo tower; for the second experiment material from the bottom layers was used. The daily ration given in the first digestibility experiment consisted of 2 kg. pulp silage and 0·25 kg. hay; in the second experiment the daily ration was 2 kg. orange-pulp silage only. The digestibility coefficients of the hay supplement used in the first digestibility test were determined in a separate experiment with the same sheep.

The composition and the coefficients of digestibility of the orange-pulp waste used are shown in Table 1. Deviations in the results of the two experiments were small and probably connected with concurrent variations in the composition of the silage feeds. The coefficients of digestibility, particularly the figures for N-free extract as determined, show good agreement with the coefficients for dry pulp previously determined by American investigators [2, 3].

Digestibility of Orange Culls

The ration fed to the experimental sheep consisted of 2 kg. sliced shamouti oranges (February crop) and 0·25 kg. barley. The digestibility coefficients of barley were determined in a separate experiment using the same sheep. The results of this experiment are given in Table 1.

Discussion

Attention may be directed to the figures for N-free extract, the most important feed constituent of both the fresh and the ensiled citrus feed. The digestibility coefficients for N-free extracts in all cases exceeded 90 per cent., a result which must be ascribed to the large quantities of sugar present (Table 1).

Comparison between the feeding-values of fresh oranges and of orange-pulp silage shows that the feeding-value of pulp silage is about 16 per cent. higher than that of whole oranges. This is due to the higher percentage of dry matter in the silage pulp. The juice present in whole oranges is rich in totally digestible sugars. Calculated to dry matter, the

TABLE 1. *Chemical Composition and Digestibility of Citrus Feeds*

No. of Expt.	Material	Date of Expt.	Dry matter %	Composition of fresh material, Per cent.					Coefficients of digestibility				Digestible nutrients as per cent. of fresh material				
				Crude protein	Fat	Ash	Crude fibre	N-free extract	Crude protein	Fat	Crude fibre	N-free extract	Crude protein	Fat	Crude fibre	N-free extract	Total digestible nutrients
1	Orange-pulp silage	Sept. 1938	16·0	1·2	0·3	0·8	2·7	11·0	56·0	65·2	80·8	95·4	0·7	0·2	2·2	10·5	13·8
2	,, ,,	Oct. 1938	15·9	1·2	0·3	0·8	2·6	11·1	50·3	65·2	72·1	91·5	0·6	0·2	1·9	10·1	13·0
Average of 1+2[1]	,, ,,	..	16·0	1·2	0·3	0·8	2·7	11·1	53·1	65·2	76·4	93·5	0·6	0·2	2·1	10·4	13·5
3	Orange culls	Feb. 1939	12·8	1·0	0·1	0·6	1·2	9·8	64·4	44·1	82·3	99·2	0·7	0·1	1·0	9·7	11·6

[1] Calculated from averages found for dry matter.

feeding-value of whole oranges, therefore, appears to be higher than that of orange-pulp silage. The feeding-value of citrus feeds compares extremely well with that of other succulent fodders, e.g., clover, alfalfa, corn, cowpea, and beet. It must be borne in mind, however, that citrus feeds contain less protein than most other fodders.

Summary

1. The digestibility coefficients of fresh orange culls and of citrus-pulp silage have been determined in experiments on sheep.

2. Attention has been directed to the importance and high digestibility of the N-free extract of fresh and silaged citrus feed.

Acknowledgement.—We are indebted to Mr. R. Volcani, who supervised the execution of the digestibility trials.

REFERENCES

1. A. BONDI and H. MEYER, Chemical Composition and Digestibility of Palestinian Cattle Fodder. Agric. Res. Stat., Rehovot, 1940, Bull. No. 27.
2. S. MEAD and H. R. GUILBERT, The Digestibility of Certain Fruit By-products as determined for Ruminants. I. Dried Orange Pulp and Raisin Pulp. Univ. Calif., Berkeley Agric. Res. Stat., 1926, Bull. No. 409.
3. W. M. MEAL, R. B. BECKER, and P. D. ARNOLD, The Feeding-value and Nutritive Properties of Citrus By-products. Univ. Florida, Gainesville Agric. Res. Stat., 1935, Bull. No. 275.

(*Received December 4, 1941*)

THE PRODUCTION OF JUTE IN BENGAL

A. S. THOMAS

(*Economic Botanist, Department of Agriculture, Kampala, Uganda*)

WITH PLATES 3 and 4

Introduction.—Two species of *Corchorus* are cultivated in India to supply jute fibre from the vascular bundles of their stems. It seems that one species—*Corchorus capsularis* L.—is truly native to India and to other countries of south-eastern Asia; the other—*Corchorus olitorius* L.—appears to have been introduced in the distant past, perhaps as a pot-herb, for this plant is widely distributed in Africa and its leaves are boiled and eaten in many countries, including Uganda.

In spite of the wide distribution of *Corchorus* species in the wild state, yet it is only in India that these plants serve as an important source of fibre. Even in India the jute industry is of recent growth: until about 150 years ago other fibre-producing plants, for example, San-hemp (*Crotalaria juncea*), were of greater importance. The first recorded export of jute from India was of 100 tons in 1793; a trade in hand-woven jute cloth developed rapidly, and in 1866 jute goods to a value of over 8 million rupees were exported. The hand-woven cloths, however, soon afterwards were replaced by the products of the Dundee mills; for by 1838 the technique of spinning and weaving had been perfected and, when supplies of Russian flax were cut off by the Crimean War (1854–6), jute rapidly displaced flax from the Dundee mills.

The first jute-spinning mill in India was set up in 1855; by 1885 there were 20 mills with 6,700 looms; by 1901 there were over 15,000 looms, and by 1940 there were over 68,000 looms. Jute mills have been started in many countries, but more than half the crop is spun and woven in India; in 1937–8 the export of jute goods amounted to over a million tons, valued at over 290 million rupees, and that of raw jute to 757,000 tons, valued at over 147 million rupees. It was estimated that the area under jute in that season amounted to nearly 3 million acres.

Very little jute is produced by countries other than India; in recent years an average of about 10,000 tons has been produced in Nepal, 9,000 tons in Formosa, and 6,000 tons in Japan. Trials of jute have been made in many tropical countries, but with little success, for in most places the bulk of fibre produced has been small and the quality poor; in Brazil quite good jute has been grown, but it is difficult to get labourers there to undertake the arduous work of growing and preparing the fibre.

Jute in India

Bengal is the great centre of jute production: it was estimated that in 1937–8 the acreage under jute in Bengal was 8·7 per cent. of the total cropped area and that it comprised 78 per cent. of the acreage under jute in India; adjacent parts of other provinces—Bihar and Assam—each accounted for 10 per cent. of the total acreage under jute. There-

fore the bulk of the Indian production of jute, and indeed of world production, is from a very compact geographical area with little variation in soil and climate.

There is no doubt that the limited distribution of the crop is due to the fact that the conditions in the area composed of the vast flood-plains of the rivers Ganges and Brahmaputra are peculiarly suited to the vigorous growth of the jute plant. The country is flat, being built up with the deposits of alluvial soil brought down by the rivers whose waters, especially those of the Ganges, are turbid with all the silt that they are carrying. During the monsoon the rivers are in flood and their levels rise greatly; often channels become silted up and the rivers change their courses, causing much damage to bridges and embankments. Some areas, the so-called 'highlands', are above the flood-level; others, the 'lowlands', are under water for part of the year; and the 'lowlands' grade into the 'char' lands or newly deposited banks of silt by the rivers.

Owing to the density of the population—in Bengal there are about 50 million people to an area of about 77,000 square miles—pressure on land is intense and little uncultivated ground may be seen in the districts where jute is grown. In the low-lying areas the houses are often built on small plots of ground whose level has been raised with soil excavated nearby—the excavations forming 'tanks' in which the water is standing for most of the year.

The system of agriculture is controlled by the fluctuations of the climate and of the water-level, for, as mentioned above, it is only the 'highlands' which are not flooded for part of the year; on the 'lowlands' the crops of rice and jute are planted before the water rises and the land is flooded. Rice is the most important crop in Bengal, and it is estimated that 23 million acres are planted with it each year.

Coconut palms and bananas are common around the houses; on the 'highlands' groves of fruit-trees, especially mangoes and jak fruit, are planted. Timber is scarce, for in addition to the fruit-trees and the large specimens of species of *Ficus* there are few other trees; bamboos are commonly grown to provide material for building and for basket-making. The pigeon pea (*Cajanus cajan*) is an important crop. Sugar-cane is planted extensively in some parts; the variety CO213 is grown almost exclusively, for it has proved to be a heavy yielder, resistant to pests and diseases, and to extremes of climatic conditions, either of drought or of waterlogging. Another sugar-producing plant which is extensively grown in Bengal is the wild date-palm (*Phoenix sylvestris*) which is carefully tapped at the beginning of the cold weather (October and November).

During the winter months, when the cool dry weather is in violent contrast to the heat and dampness of the climate in summer, other crops are grown; various types of mustard, whose oil is used in cooking, are sown over large areas; lentils (*Lens esculenta*) and gram (*Cicer arietinum*) are important pulse crops at this season.

Large numbers of live stock are kept: it is estimated that there are about 25 million cattle in Bengal, and millions of buffaloes, goats, and poultry. Most of the cattle are of a poor type, small and producing little milk; but some cows have given as much as 5,000 lb. in a lactation.

and it is hoped to grade up the cattle population by the use of bulls from heavy-milking families. Cattle and buffaloes are used for ploughing and for drawing carts; few lorries may be seen, as the number of rivers and creeks precludes the construction of many good roads. In the lower areas the peasants use small boats along the creeks and inlets to connect up with the steamer services on the wider rivers, which are the main channels of transport.

Agricultural conditions in the jute-growing areas.—The most important jute areas are all on the alluvial deposits of the plains beside the rivers Ganges and Brahmaputra. The new deposits are very fertile, being rich in plant-foods, with a high potash-content; the alluvium from the Ganges also is very rich in lime. These alluvial soils vary in texture, and it has been found that jute grows best on well-drained friable loams; adverse weather may cause a failure of the crop if it is planted on clays or sands. Older deposits are less fertile because they are less easy to cultivate, they are poorer in plant-nutrients, and have a lower alkaline reaction; often they are partially 'laterized', becoming redder in colour and richer in soluble iron and aluminium compounds. Some of the soils on the farm of the Bengal Department of Agriculture at Dacca are of this type, having a pH value of 6·6; it has been found that lime and potash must be added to such soils if satisfactory crops are to be obtained, for without such manuring much of the jute dies of root-disease (*Rhizoctonia*). The disease has caused much damage to jute when it was tried in Uganda on soils relatively poor in potash and lime, and it is probable that the deficiency of bases in the soil was primarily responsible for the attack of the fungus; furthermore, it may be mentioned that the most vigorous wild plants of *Corchorus olitorius* seen in Uganda were growing on 'black cotton soil' in Karamoja, one of the few stretches of soil in the protectorate which are rich in lime.

As with the soil, so also with the climate, there is a great similarity between the various jute-growing areas of India which, even though they may be hundreds of miles from the coast, yet are less than 100 ft. above sea-level. The climate is characterized by high temperature and high humidity during the growing-period of the jute; for all the five months from May to September inclusive, when the crops are growing vigorously, the average maximum temperature is over 90° F., the average minimum temperature is over 70° F., and the average atmospheric humidity is 80–90 per cent.; a total of about 60 in. of rain is distributed during the five months of the growing-period. These conditions cannot be matched in Uganda, nor is it probable that in many parts of East Africa can be found the same combination of high temperature and high humidity for as long as five months. It may be that, in addition to the temperature and the humidity, the length of day is an important factor in the development of the jute plant, for the jute areas of Bengal lie between 23° N. and 27° N., where there are more hours of daylight in the summer months than on the equator. Jute has been tried without success in many tropical countries and, even in south India, where the climate is moist and warm but the days are never so long as those of the summer in Bengal, it is not an important crop.

Jute species grown in Bengal.—Three-quarters of the jute produced in India is derived from *Corchorus capsularis*: the other quarter is from *Corchorus olitorius*. The latter is the predominating species only in the districts to the immediate north of Calcutta where much of the country-side is of 'highlands' above the flood-level, for *Corchorus olitorius* will not tolerate flooding for any considerable length of time. *Corchorus capsularis* is more hardy, withstanding a wider range of conditions, both of drought and of flooding; it has the advantage of being quicker to mature and, if it is sown early, it may be cut in time for an autumn crop of rice to be grown in the same ground. On some of the lowest fields *Corchorus capsularis* is sown as early as March in order that it may be harvested in June, before the rivers rise too high; for although prolonged flooding does not kill this species, yet it spoils the quality of the fibre, causing the plants to produce adventitious roots below the surface of the water and the vascular bundles of the stem to become knotted.

The two species, as grown in Bengal, are similar in habit, with stout straight stems unbranched to 6 or 8 ft. and attaining a total height of 8 ft. or more. There is little difference between the appearance of the leaves, but those of *Corchorus capsularis* are bitter in taste and on that account are much less often used as a pot-herb than those of *Corchorus olitorius*, which are sweet. The species differ greatly in the shape of their fruits—those of *Corchorus capsularis* are round and those of *Corchorus olitorius* are elongated. The fibre from the stems of the two species also differs: that from *Corchorus olitorius* is finer and stronger than that from *Corchorus capsularis* and therefore it often fetches a higher price. But, on the other hand, it seems that usually *C. olitorius* gives the smaller yield per acre; in 1937–8 large-scale inquiries showed that it averaged only 10·4 maunds (a maund equals 82 lb.) per acre as compared with 12·7 maunds per acre from *Corchorus capsularis*.

Cultivation and treatment.—Methods of cultivation for the two species are very similar; the land is thoroughly worked to produce a fine tilth before sowing and as many as eight ploughings may be given; the seed is broadcast at a rate of about 9 lb. per acre, or is drilled in rows 6 in. apart at a rate of about 4 lb. an acre and is raked in. Most of the seed is home-grown, for many of the peasants reserve a small part of their jute crop (about 4 per cent.) to provide seed for the next season, although improved strains are grown on a considerable scale in Bihar to provide seed for sale in Bengal. The crop is weeded twice and the seedlings are thinned to a spacing of from 4 to 6 in. Jute plants are attacked by a root-disease (*Rhizoctonia*), which is especially pernicious to young seedlings, causing them to damp off; in older plants portions of the stem are affected; *Sclerotium Rolfsii* also damages mature plants. The most important insect pests are a small weevil (Jute Apion) which bores into the stem, damaging the fibre, and caterpillars which attack the leaves. The numerous ploughings, the weeding and thinning by hand, make jute an expensive crop to cultivate, and it is estimated that the cost of bringing one acre to the harvesting stage is about 50 rupees.

Jute is ready for harvesting when the fruits have set; a poor yield and weak fibre are obtained if the plants are cut before or during the flower-

ing stage, and this is done only when the fields are threatened with deep flooding; if the harvesting is delayed until the fruits are ripe, larger yields are obtained, but the fibre is of less value on account of its coarseness. The early sown *Corchorus capsularis* growing on the lowlands is harvested between the middle of June and August, whilst the later crops on the highlands are cut in August and September. *Corchorus olitorius*, which is sown later and has a longer growing-period, is harvested mostly in September and October.

In order to obtain the maximum lengths of fibre, the plants are cut with sickles close to the ground, and in flooded fields of *Corchorus capsularis* it is necessary for the workers to dive under water to do this work. The plants are tied in bundles and, if the fields are flooded, the jute is carried directly to the pools for retting; if the fields are not flooded, the bundles are left for 2, 3, or 4 days in order that the leaves may be shed. The loss of leaves is advantageous, for it greatly reduces the weight of material to be transported and, as the leafless stems are the more easily submerged, more even retting may be secured.

Retting is carried out in streams, pools, and borrow-pits. The water should be at least 4 or 5 ft. deep in order that the bundles may be submerged below the surface, being weighted down by earth, stones, or the Water Hyacinth which is so abundant a weed in Bengal, and that the jute may yet be above the mud at the bottom of the pool which would discolour the fibre. In the 'highland' areas much of the jute is retted in more shallow borrow-pits, for the bulk of green jute is so heavy as to preclude transport for any considerable distance. The question of water-supplies in jute areas is of great importance not only for the retting but also for the washing of jute and, as the retting process takes from 14 to 25 days, even under the high temperatures of the harvest months in Bengal, large amounts are needed. It is essential that the retting-pools should be distinct from the supplies of drinking-water, for the evil-smelling by-products of the retting greatly pollute pools and streams; in fact, when the workers have to stand in the foul water for long periods while washing the fibre, their skin is affected. If the retting water is not fairly clean, the quality of the fibre deteriorates; in Bengal the fibre retted in the clean water of the river Brahmaputra is of much better colour than that retted in the turbid water of the river Ganges and its tributaries; muddy water gives a dark colour to the jute and, if the water is coloured with salts of iron, the fibre is nearly black.

After the jute has been retted, the strands of fibre are stripped from the stems; usually the woody portion of the stem remains unbroken in the form of a stick 6 or 8 ft. long, and large stacks of these sticks may be seen beside the retting-pools and in the villages after the jute harvest. These sticks have been shown to be suitable for paper-making; but their bulkiness renders their utilization uneconomic on account of the costs of transport, and therefore they are used by the peasants for making fences or for fuel. The fibre is washed, dried in the sun for a few days, and tied in bundles for sale.

Yields, marketing, and costs.—Jute is a very bulky crop: it has been estimated that on the average it produces about 13 tons of green material

per acre, with an out-turn of about 6 per cent. of fibre. Inquiries have shown that the mean area of jute per grower is about 1½ acres, usually made up of a number of small plots each one-quarter or one-third of an acre. Therefore at harvest time there is more material than can be dealt with by the peasant and his family; outside help must be secured, sometimes on the basis of mutual assistance and sometimes as hired labour. It has been estimated that if labour were hired at the average rate of pay in the jute areas, which is about 6 annas a day, the cost of cutting, retting, stripping, washing, and drying the fibre is about 2 rupees for each maund.

Most of the peasants have no suitable space for storing their jute; many are in debt, and are so much in need of money that they are forced to sell their jute as soon as it is prepared. Therefore almost the whole crop is sold before December in each year. Three-quarters of the total production of jute is sold to travelling buyers who visit the villages; about one-fifth is sold to primary markets in the larger villages, and only 5 per cent. is sold at the baling centres. The jute often passes through the hands of several middlemen before it is purchased by the large firms, and there is no doubt that these dealers by their malpractices have a very bad influence on the jute trade: they use various excuses (ranging from deductions for possible mistakes in weighing to allowances for charities) to reduce the price paid to the growers, they transport jute from districts of low quality to those of higher quality in order to secure better prices, and they water the fibre in order to increase the weight, thereby spoiling the quality, for if wet fibre is stored its colour and strength deteriorate. Eventually the jute reaches the larger firms, who grade it and bale it for transport to the local mills or for export.

It has been estimated that, with hired labour, it would cost about 6 rupees to grow, prepare, and market a maund of jute. A grower with an average area of 1½ acres and an average crop of 12 maunds per acre would have 18 maunds of jute to sell. The average harvest prices of jute in Bengal increased slowly from Rs. 3/8 in 1932–3 to Rs. 6/- per maund in 1938–9. As much of the labour of production would be supplied by the grower and his family, jute would afford a fair profit to the grower in good years, but in seasons of poor prices there would be little cash return for all the labour expended.

The dislocation of trade by the war has seriously affected the jute industry and prices once more have fallen to a level which gives little return to the growers. The Government of India, in consultation with the interests concerned, has decided that prices must be stabilized and the area under the crop drastically restricted. In order to counteract the over-production, the Indian Central Jute Committee in its research laboratories is seeking for other methods of utilizing jute; the plant-breeding section at Dacca is selecting improved strains which will combine larger yields with a better quality of fibre. The ultimate fibres of jute are so short that it cannot be woven into cloth of good quality unless it is blended with better fibres, such as flax; and canvas woven from jute will not be durable unless it is impregnated with preservatives.

Possibilities of Jute-growing in Other Countries

It is improbable that jute could be grown successfully on a large scale in Uganda. No part of the country is subject to sufficiently long hot and wet spells of weather; there are no large stretches of friable alluvial soils, rich in lime; and, furthermore, few areas would have the ample supplies of water necessary for retting and washing the fibre. Nor is it likely that the African would willingly undertake all the strenuous labour involved in cultivating and preparing the crop unless he could secure much better returns than seem probable in the near future.

Jute has been tried in many other countries near the equator, including some countries where the climate, in respect of rainfall, humidity, and temperature, resembles that of the summer months in Bengal; but the crop has seldom been a success. It may be that the length of day is an important factor in controlling the growth of the plant for, as pointed out above, there are more than 12 hours of daylight during the summer months in north India. But it is certain that soils resembling those of the alluvial plains of the river Ganges and the river Brahmaputra, soils which are friable, well drained, and rich in lime and potash, cannot be common in the hotter, more humid parts of equatorial Africa. Nor is it likely that such soils would persist in any places near the equator where there are sufficient supplies of water to ret the jute crop, for under the action of an equatorial climate the bases would be rapidly leached out. There seems to be little doubt that the poor growth of jute, reported from many countries inside the tropics, has been due to the fact that the soils were unsuited to the crop. Heavy manuring with lime and potash would be needed if jute were to be grown successfully on such soils and, unless the price improved greatly, this procedure would be uneconomic. It appears unlikely, therefore, that it will be worth while to make trials of the crop except in places where there is recent alluvium or a young volcanic soil in close proximity to ample supplies of water, and where there is a high temperature and a high humidity for a season of five months.

Summary

1. A brief description is given of the methods of cultivation and preparation of jute in Bengal and of the conditions under which it is grown.

2. The jute crop has especial requirements—a hot humid climate in the growing-season, an ample supply of water for retting, and a friable soil rich in potash and lime. It is unlikely that jute will be a profitable crop except in countries where these requisites are fulfilled.

Acknowledgements.—Grateful acknowledgement is made of the kind hospitality and assistance extended to me during my visit to Bengal by the Director of Agriculture and by the scientific staff of the Indian Central Jute Committee.

(*Received January 28, 1942*)

FIG. 1. Jute-breeding plots at Dacca. Recently cut plants are lying on the ground, while the border rows are still standing

FIG. 2. Retting jute; bundles of stems, weighted with weeds, being fastened down in a pool

FIG. 3. Stripping jute; three stems are held in the right hand while the fibre is pulled off with the left hand

FIG. 4. Washing jute in a pool

RABBIT-FEEDING IN WAR TIME

DENNIS PAGE

(*School of Agriculture, Cambridge University*)

Part I. The Reduction of Concentrated Food Rations

In war time high-class concentrated foods cannot be spared for rabbits: such foods are of much greater importance for milk production. For this reason it was thought important to determine just how far the rabbit industry could carry on with only such foods as the garden and allotment can supply.

The first step was to determine whether or not rabbits could be bred and reared successfully without any concentrated food at all, i.e. on hay, roots, and green food only. Hitherto it has been agreed that some concentrated food is necessary, although the claim is made from time to time that green-stuff and hay alone are sufficient. As work proceeded it became increasingly clear that although hay and green food showed possibilities as a maintenance ration, they were insufficient for a production ration.

The next step was to determine just how much concentrated food was essential to ensure healthy litters and good meat-production. Let it be said at once that these experiments have shown this requirement to be far in excess of the ration at present issued by the Ministry of Agriculture, viz. 28 lb. per breeding doe per year. Thus it seems that if rabbits are to be bred and reared successfully, either there must be an increase in the present official ration, or some supplementary food of higher nutritional value than hay, roots, or green food must be used.

In the second part of this paper it is shown that cooked potatoes can be substituted for the more usual oats, maize, or bran: and there seems no reason why the rabbit industry should not be carried on in this way so long as an excess of potatoes can be grown in this country.

Stock and Feeding.—The does used in this experiment were all cross-bred, usually reaching a maximum live weight of 5 to 6 lb. These were mated with two bucks, one a pure Blue Beveren of adult live weight 8 lb., the other of live weight 7 lb. In-breeding was avoided by introducing a third buck (adult live weight 8 lb.) for use with third-generation does.

Table 1 shows the percentage of fertile matings for each month. From this it is clear that the best breeding-time is from February to April, and the worst is from September to November. All litters were weaned at 48

Table 1. *The Monthly Variation in Percentage of Fertile Matings taken for One Year*

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
No. of matings	16	27	13	26	17	22	12	13	14	17	25	20
Fertile matings, per cent.	44	74	84	73	71	64	42	23	7	29	20	50

days from birth irrespective of weight or condition. Litter mates were kept together until they were 88 days old, being then transferred to single cages until they were 188 days old (approximately 6 months), when they were of good killing-size, or if does, were suitable for breeding.

The stock was fed twice daily. Fresh hay was given each morning with the concentrate ration (if any) and green food or roots in the afternoon. The hay varied from rough mowings from the poultry-runs to good-quality clover hay.

Green stuff varied with the time of year, but mainly consisted of mangolds in winter (i.e. November to April or May) and cabbage and lawn trimmings in the summer months. Owing to the difficulty of measuring the amount of lawn trimmings consumed, food-consumption figures given below refer only to the period of winter feeding, when mangolds, with occasional feeds of cabbage, formed the succulent ration.

The three bucks received a normal ration throughout the experiment, i.e. hay and green food *ad lib.*, with 4 oz. of a mixture of flaked maize, bran, and crushed oats per day. Resting does received hay and green food only. Great care was taken to see that each rabbit had these foods supplied *ad lib.* All stock had water throughout the hot summer months, and during the winter it was given to does suckling their young.

Concentrated food rations after kindling.—It was decided to use oats as the standard form of concentrated food in the tests about to be described. As already mentioned, all the does received as much hay and green food as they chose to consume. They were divided into five groups on varying quantities of oats, viz.:

(i) *Four oz. oats daily to weaning* (*'full-corn'*). This was similar to the normal pre-war ration when feeding-stuffs were plentiful. The weight of oats used per litter was thus 192 oz.

(ii) *Two oz. oats daily to weaning* (*'half-corn'*).

(iii) *No corn.* On this treatment does merely continued on their 'resting-stage' feed of hay and succulents, with no concentrated food whatsoever. The aim was to determine whether a production ration could be built up without concentrated food.

(iv) *Corn to 18 days.* In addition to hay and succulents, oats were fed as follows:

1st day after kindling to 12th (incl.)	4 oz. oats per day
13th and 14th day	3 oz. oats per day
15th and 16th day	2 oz. oats per day
17th and 18th day	1 oz. oats per day
19th day to weaning	no oats

The total weight of oats needed per litter was 60 oz.

(v) *Corn to 8 days.* In addition to hay and succulents, oats were fed as follows:

1st and 2nd day after kindling	4 oz. oats per day
3rd and 4th day	3 oz. oats per day
5th and 6th day	2 oz. oats per day
7th and 8th day	1 oz. oats per day
9th day to weaning	no oats

The total weight of oats needed was 20 oz. per litter.

From these last two treatments it was hoped to find whether concentrates could be spared during the later stages of lactation.

Feeding of the young after weaning.—In general, all young received hay and succulents only from 48 days (weaning) to 88 days, so that any differences due to pre-weaning treatment might be shown. The one exception was the treatment of young from the does on the 'full-corn' ration. These were allowed 1 oz. of oats per head per day, thus providing a standard of reference.

Feeding from 88 days onwards.—From 88 days onwards the rabbits were subjected to three different treatments as follows:

Group I. Rabbits in this group continued with their hay and succulent ration to show whether young could be grown to a suitable killing-weight without concentrates.

Group II. Rabbits in this group received 1 oz. oats per day in addition to hay and succulents.

Group III. Rabbits in this group received 2 oz. oats per day in addition to hay and succulents.

Condition of the doe during lactation.—In general it was found that a ration of at least 4 oz. of oats per day was required to prevent loss of weight in lactating does. This loss was fairly constant for does on all the other reduced corn treatments, but was not serious.

Mortality figures of the young.—Table 2 shows mortality figures of all young to 88 days after birth. Though numbers are small, the following points are nevertheless apparent from the table:

If litter size was unrestricted, only the 'full-corn' ration (4 oz. oats daily) gave a reasonable survival-rate.

A fair percentage of young in litters up to and including 8 survived on the 'full-corn' ration.

TABLE 2. *Mortality Figures of Young Rabbits*

Doe ration		*Number of young in litter*								*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
Full-corn	Average no. in litter	..	..	..	..	..	..	..	..	5·2
	No. of litters	1	1	2	..	2	2	3	2	13·0
	Survival to 48 days, %	100	100	83	..	100	75	57	81	76·5
	Survival to 88 days, %	100	100	83	..	100	75	52	81	75·0

Doe ration		*Number of young in litter*								*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
Half-corn	Average no. in litter	..	..	..	..	..	..	..	..	5·5
	No. of litters	..	1	..	2	3	3	3	1	13·0
	Survival to 48 days, %	..	100	..	88	67	44	38	25	52·7
	Survival to 88 days, %	..	100	..	88	67	38	5	0	32·4

TABLE 2. *Mortality Figures of Young Rabbits (continued)*

Doe ration		*Number of young in litter*								*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
Corn to 18 days	Average no. in litter	..	..	..	..	..	..	..	..	5·5
	No. of litters	1	1	1	2	6	5	5	3	24·0
	Survival to 48 days, %	100	100	100	50	93	75	21	16	48·2
	Survival to 88 days, %	100	100	100	50	60	61	9	4	31·7

Doe ration		*Number of young in litter*								*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
Corn to 8 days	Average no. in litter	..	..	..	..	..	..	..	..	4·4
	No. of litters	3	2	5	2	4	3	3	2	24·0
	Survival to 48 days, %	100	25	60	63	65	33	24	38	45·7
	Survival to 88 days, %	100	25	47	50	25	17	14	38	31·4

Doe ration		*Number of young in litter*								*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
No corn	Average no. in litter	..	..	..	..	..	..	..	..	4·3
	No. of litters	2	1	1	1	2	3	..	1	11·0
	Survival to 48 days, %	50	50	100	75	40	33	..	0	38·3
	Survival to 88 days, %	0	0	33	75	0	33	..	0	21·3

A fair percentage of young in litters of 5 and under survived on the 'half-corn' ration.

A fair percentage of young in litters of 6 and under survived on the 'corn-to-18-days' treatment.

Both the 'corn-to-8-days' treatment and the 'no-corn' treatment gave exceedingly poor survival-rates, and even in the smallest litters a fair survival-rate could not be guaranteed.

Conclusion: In litters of 6 young or less the 'corn-to-18-days' ration was the most economical. Attempts to rear litters without the use of concentrates are unlikely to succeed.

Rate of growth of young during suckling and up to 88 days.—It is obvious that the rate of growth of young is influenced by the number of young in the litter, and for this reason the growth-curves are arranged in three groups:

Group I: For small litters of 1, 2, and 3 young (Fig. 1).

Group II: For medium litters of 4, 5, and 6 young (Fig. 2).

Group III: For large litters of 7, 8, and 9 young (Fig. 3).

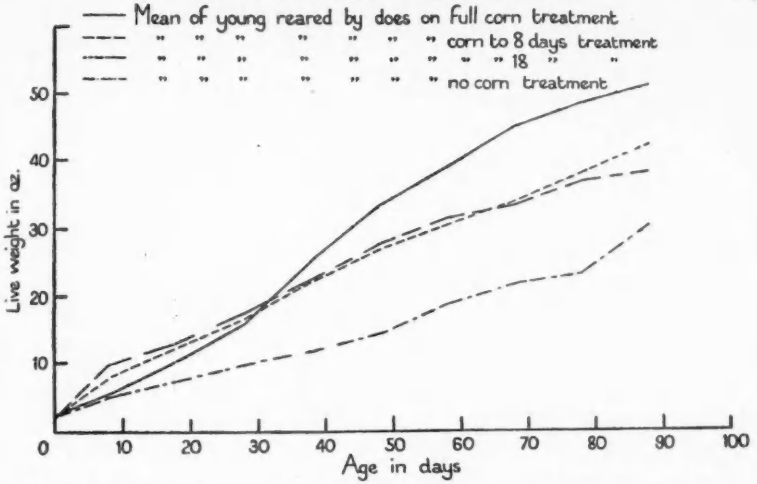


FIG. 1. Mean growth-curves of young from 0–88 days for litters of 1, 2, and 3 young.

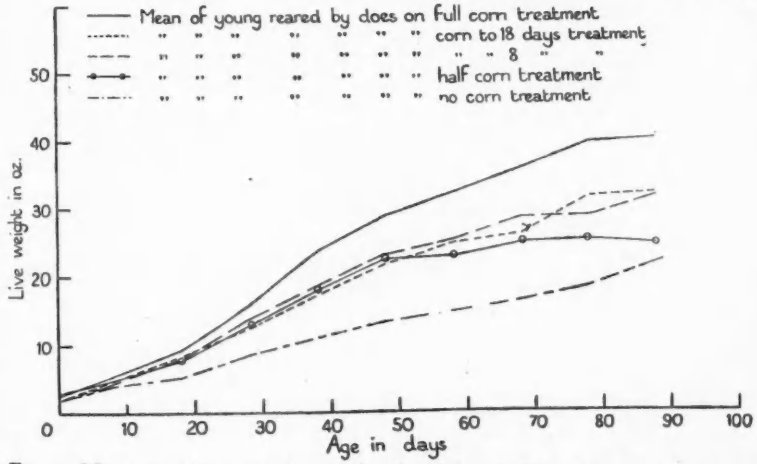


FIG. 2. Mean growth-curves of young from 0–88 days for litters of 4, 5, and 6 young.

By such grouping it is possible to include litters in which one or two young die during suckling: for example, if 2 die out of a litter of 6 the remaining 4 still fit into Group II. Litters in which a large proportion died could not be included.

The growth-curves are continued beyond weaning up to 88 days in order to show any delayed effects from the treatment during the suckling-period.

Conclusions from Fig. 1.—(1) There was considerable difference between the young reared by does on a 'full-corn' ration and those on a 'corn-free' ration. The average weight of rabbits at weaning from does on 'no-corn'

was only 55·9 per cent. of the mean of those reared by does on the 'full-corn' ration.

(2) There was little difference between young from does on the 'corn-to-18-days' and 'corn-to-8-days' treatment.

Conclusions from Fig. 2.—(1) Here again the small difference between young from does on the 'corn-to-18-days' and 'corn-to-8-days' treatments was apparent. Also, young from does on the 'half-corn' treatment gained weight at approximately the same rate as these.

(2) It is clear that the growth-rates of young from does on all the corn treatments have been slowed down as compared with those in Fig. 1, but approximately the same percentage difference still exists between the growth-rates of young from each of the separate treatments.

Conclusion from Fig. 3.—In this group only young from does on the 'full-corn' ration could be represented, as no litters survived on any of the other treatments.

Thus in general the young reared by does on the three intermediate corn treatments grow at approximately the same rate, comparing quite favourably with the normal well-fed rabbits. The survivors of families from does on hay and succulents alone grow much less satisfactorily.

Effect of litter-size.—From Figs. 1 and 2 (representing growth-rate of small and medium litters resp.) it is clear that difference in litter-size does affect the rate of growth of young on all the treatments. As already mentioned a general comparison cannot be made between litters of the three groups, small, medium and large, as those of the last group survived only on the 'full-corn' ration.

Fig. 3 gives mean growth-curves of small, medium, and large litters from does on the 'full-corn' ration; it also gives a measure of the effect of litter-size on growth-rate of the young from this one treatment. There seems to be little difference in growth-rate to weaning between litters of 1–6 in number, but those of 4, 5, and 6 young 'tailed off' immediately after weaning. There was a much greater difference between the weaning-weights of medium- and large-sized litters.

The number of litters from which the above curves were taken was small. This is probably the reason why the growth-rate of the young of the 4, 5, and 6 group slowed down after 78 days, and no great significance can be attached to it.

Growth-rate of young from 88 days to killing-size.—Fig. 4 shows the mean-growth curves of young for this period for rabbits from three groups mentioned previously, i.e. *Group I* on hay and succulents alone; *Group II* on additional 1 oz. oats per day; and *Group III* on additional 2 oz. oats per day. The graphs show that there is little difference between the growth-rates of rabbits receiving 1 or 2 oz. oats per day, but the growth-rate of rabbits on hay and succulents alone compares unfavourably with both of these.

Average live-weight gains as shown by the graphs:

	Total gain over 100 days
Mean of rabbits on hay and succulents alone . .	28·75 oz.
,, ,, receiving add. 1 oz. oats . .	43·5 oz.
,, ,, receiving add. 2 oz. oats . . .	46·5 oz.

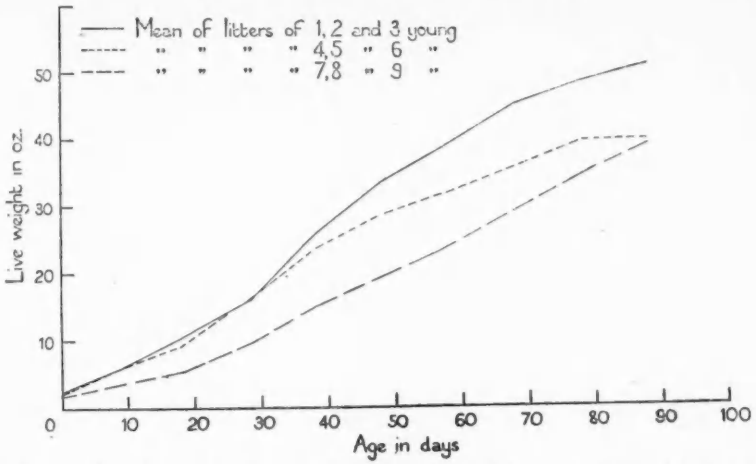


FIG. 3. Growth-curves of young from does on the 'full-corn' treatment to show the effect of litter-size on rate of growth.

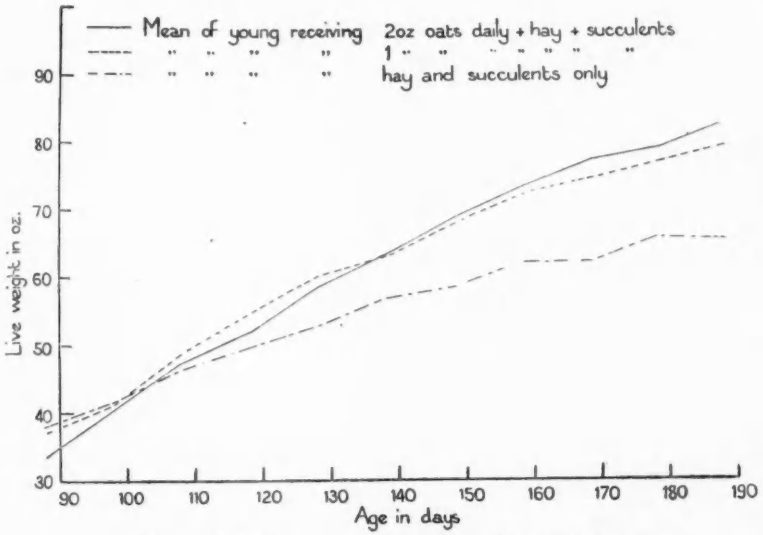


FIG. 4. Growth-curves of young from 88 to 188 days.

It follows that the small difference between rabbits on 1 oz. oats per day and those on 2 oz. oats per day does not warrant the feeding of the latter ration, particularly in war time.

TABLE 3. *Food Consumption*

Treatment	*D.M. per 1 lb. L.W.I. in lb.*	*lb. D.M. in food per 1 lb. Ed. D.M. in carcass*	*lb. hay per 1 lb. L.W.I.*	*lb. mangolds per 1 lb. L.W.I.*
No corn .	12	65	8·5	33·3
Oats 1 oz. .	10·2	50	6·0	21·8
Oats 2 oz. .	8·9	42	4·4	13·0

The above data represent food-consumption figures for rabbits up to 188 days, when they were of suitable killing-size. The figures are given as the mean intakes of 44 rabbits in all, 20 on the 'no-corn' ration and 12 on each of the other two. Weights in the third and fourth columns are fresh weights. The dry-matter weight of food eaten to produce 1 lb. dry matter of edible flesh (given in column two) is derived from the dry matter of food eaten per 1 lb. live-weight increase (column one) by following King Wilson's estimation that 33 per cent. of rabbit flesh is dry matter.[1]

It appears also that the greater the oat ration allowed per rabbit then the smaller is the total dry-matter requirement. Thus by using highly concentrated foods the amount of dry matter of food required to produce 1 lb. live-weight increase is reduced. This is the most probable explanation why the food-consumption figures given here compare unfavourably with those accepted as the standard in peace-time.

Summary

1. *Condition of the doe during lactation.*—Four ounces of oats per day gives considerably better results than any of the other treatments using less corn, but is impracticable in war time. There is little difference between the other treatments.

2. *Mortality of the young.*—The 'corn-to-18-days' treatment is the most satisfactory restricted corn ration when litters are below 7 in number. Excess young must be removed at birth, otherwise the doe usually tries to keep all alive, with the result that all become underfed and probably die.

3. *Growth-rates of young to 88 days.*—Results from the three treatments, 'corn-to-8-days', 'corn-to-18-days', and 'half-corn' to weaning are similar, comparing fairly well with those from the 'full-corn' ration.

4. *Growth-curves from 88 days onwards.*—From observations on live-weight gains it seems that 1 oz. oats should be the maximum allowance per head per day in war time; 2 oz. oats probably produces a better carcass, but the better finish does not justify the extra feed.

5. *Maintenance of breeding stock.*—It is generally agreed that hay and green food alone do not provide a sufficient production ration. Results have confirmed this conclusion. These experiments, however, do show that hay and green food constitute a sufficient maintenance ration. Thus it can be said that in war time does which are not suckling young should be allowed no concentrated foods.

[1] W. King Wilson, The composition of some rabbit carcases. J. Min. of Agric., 1930, **36**, No. 12.

From these observations the following combination of rations seems ideal for war-time requirements:

Resting does: hay and succulents only.

Lactating does: 'oats-to-18-days' treatment, i.e. 60 oz. oats per litter.

Young, 48–88 days old: hay and succulents alone.

Young, 88–188 days old: 1 oz. oats per day+hay+succulents.

Assuming that a doe rears 3 litters averaging 5 young each per year (i.e. produces 15 young per year) the amount of oats needed if the above plan is carried out is:

For the 3 lactation periods, 180 oz.

For the rearing periods, 1500 oz.

The total is 1680 oz. or 105 lb.

The present ration allowed by the Ministry of Agriculture is 28 lb. per breeding doe per year. Thus if it is assumed that the difference in feeding-value of oats and bran is small, it appears that rabbit-keeping is not profitable, or even possible, unless some extra food can be used to form part of the concentrate ration.

Part II. The Use of Potatoes as a Concentrated Food

With stock similar to that used in the first experiments, trials were carried out to see if the necessary concentrated ration could be supplied, wholly or in part, by potatoes. The general conditions were similar to those in the previous experiments. Resting does received hay and green food only. They were drafted on one of the following treatments after kindling:

(1) 16 oz. potatoes per day to weaning.

(2) 12 oz. potatoes per day to weaning.

(3) 8 oz. potatoes per day to weaning.

Maiden does that had been reared on potatoes merely carried on with one of these rations after kindling.

The young were weaned at 48 days as before, each receiving 4 oz. potatoes per day in the period 48–88 days. At 88 days the young were split up between the three treatments:

(1) No potatoes.

(2) Potatoes, 4 oz. per day.

(3) Potatoes, 8 oz. per day.

All weights of rations refer to raw potatoes. Cooking was carried out in ordinary kitchen steamers. The cooked potatoes were well mashed and fed while still warm. They were eaten most readily when dry, soft, and crumbly, as opposed to a wet, sloppy state. Only in very few cases was it difficult to get the stock to start eating potatoes: throughout the whole experiment only one doe could not be persuaded to eat them, and in two border-line cases a short period of starvation produced the necessary inducement. In general, does coming on to potatoes for the first time cleared up their full ration on the second or third day after kindling.

Condition of the doe during lactation.—Does on the 16 and 12 oz. potato rations maintained their weight during lactation just as well as

those on a 4 oz. oats ration. Thus no drastic difference in condition of the doe was brought about by the substitution of potatoes for oats.

Mortality figures of the young.—Table 4 shows mortality figures of all young in the period 0–88 days. The following points are apparent from the table:

(1) Both the 16 and 12 oz. potato rations compare favourably with the 'full-corn' figures. Later work has indicated that 12 oz. potatoes may not be a sufficient ration for maintaining litters of 8 or 9 young.

(2) The 8 oz. potato ration produced much poorer results and did not seem a sufficient ration for raising litters satisfactorily.

(3) The limiting number of young per litter which could exist on the two treatments 16 and 12 oz. potatoes daily was very high (above 9 in the former case and approximately 7 in the latter).

TABLE 4. *Mortality Figures of Young Rabbits*

Doe ration		*Number of young in litter*									*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
Full-corn	Average no. in litter	..	..	..	..	..	..	..	..	..	5·2
	No. of litters	1	1	2	..	2	2	3	2	..	13·0
	Survival to 48 days, %	100	100	83	..	100	75	57	81	..	76·4
	Survival to 88 days, %	100	100	83	..	100	75	52	81	..	75·0

Doe ration		*Number of young in litter*									*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
16 oz. potatoes per day	Average no. in litter	..	..	..	..	..	..	..	..	..	7·0
	No. of litters	..	..	..	..	1	2	2	2	1	8·0
	Survival to 48 days, %	..	..	..	..	60	83	100	88	89	87·5
	Survival to 88 days, %	..	..	..	..	60	83	84	88	89	83·9

Doe ration		*Number of young in litter*									*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
12 oz. potatoes per day	Average no. in litter	..	..	..	..	..	..	..	..	..	6·2
	No. of litters	..	..	..	..	1	3	2	..	..	6·0
	Survival to 48 days, %	..	..	..	..	100	72	93	..	..	83·8
	Survival to 88 days, %	..	..	..	..	60	67	93	..	..	75·7

TABLE 4. *Mortality Figures of Young Rabbits (continued)*

Doe ration		*Number of young in litter*									*Total or average*
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
8 oz. potatoes per day	Average no. in litter	..	..	..	..	..	..	..	..	..	6·3
	No. of litters	..	..	..	..	3	2	3	..	1	9·0
	Survival to 48 days, %	..	..	..	..	40	100	57	..	67	63·2
	Survival to 88 days, %	..	..	..	..	40	67	38	..	56	47·4

Growth-rate of the young during suckling and up to 88 days.—Figs. 6 and 7 show mean growth-curves of young reared by does on the three potato-rations, with the 'full-corn' curves reproduced for a standard of

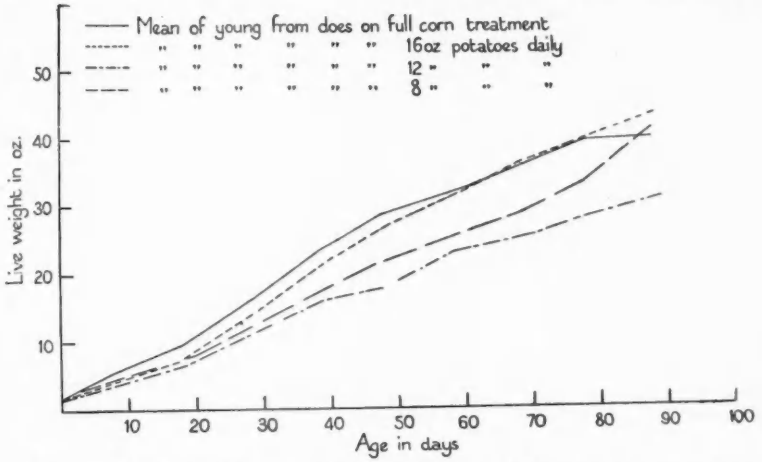


FIG. 5. Mean growth-curves of young from 0 to 188 days for litters of 4, 5, and 6 young.

reference. No data are available for small-size litters, so the graphs are divided into two groups:

(1) Medium litters of 4, 5, and 6 young (Fig. 5).

(2) Large litters of 7, 8, and 9 young (Fig. 6).

The following points are apparent from the graphs:

From Fig. 5:—(1) Young from the 16 oz. potato ration compared favourably with the 4 oz. oats standard.

(2) The rate of growth of young from the 12 oz. potato ration was less than that of young from the 8 oz. ration. This difference in rate of growth increased towards the end period (from 70 to 90 days) and a difference of 11 oz. existed between the average of the two groups at 88 days. Whether this difference repeats itself only further experiments will show.

From Fig. 6.—Here again the 16 oz. potato ration compared favourably

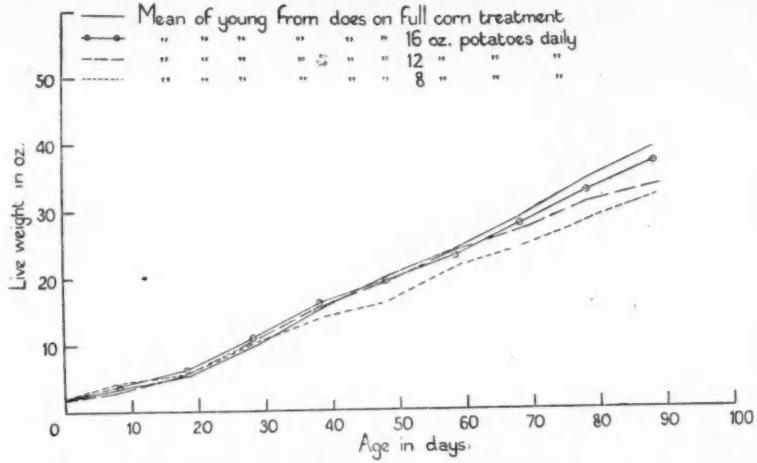


FIG. 6. Mean growth-curves of young from 0 to 88 days for litters of 7, 8, and 9 young.

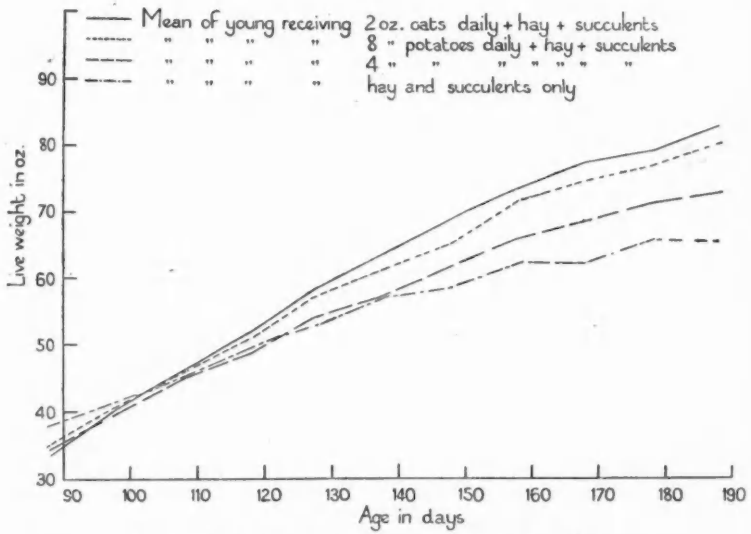


FIG. 7. Growth-curves of young from 88 to 188 days.

with the 4 oz. oats ration. The 12 and 8 oz. potato rations followed on fairly closely in that order.

Conclusion: Young rabbits reared by does on the 16 oz. potato ration appeared to live and grow just as well as those from does on a 4 oz. oats ration. Young from does on the 8 and 12 oz. potato rations did not gain

weight so rapidly, but nevertheless reached satisfactory weights as judged by war-time standards.

Growth-rate of the young from 88 to 188 days.—Fig. 7 shows the mean-growth curves for rabbits from 88 to 188 days of age. Those receiving 4 oz. and 8 oz. potatoes per day are shown, with the curves for 'no-corn' and 2 oz. of oats reproduced from the first experiment for comparison. It is seen that rabbits getting 8 oz. potatoes per day compare favourably with those on 2 oz. oats per day, with the rabbits on 4 oz. potatoes lying between these and those on 'no-corn'.

Live-weight gains from the figure:

	Total gain over the 100 days
Mean of rabbits on hay and succulents alone .	28·75 oz.
,, ,, add. 4 oz. potatoes per day .	39·7 oz.
,, ,, add. 8 oz. potatoes per day .	47·0 oz.
,, ,, add. 2 oz. oats per day . .	46·5 oz.

These average live-weight gains are taken from Fig. 7. They emphasize that rabbits receiving 8 oz. of potatoes per day gained weight at about the same rate as those getting 2 oz. oats per day.

Food-consumption.—The following figures for food-consumption are taken from a small number of samples, and so it is unsafe to generalize from them. Nevertheless, there are a few facts which can be regarded as pointers. Food-consumption figures of potato-fed rabbits, with corresponding figures for oat-fed rabbits (obtained from the first experiments) are appended:

TABLE 5. *Food Consumption*

Treatment	*D.M. per 1 lb. L.W.I. in lb.*	*Lb. D.M. in food per 1 lb. Ed. D.M. in carcass*	*Lb. hay per 1 lb. L.W.I.*	*Lb. mangolds per 1 lb. L.W.I.*
No corn .	12	65	8·5	33·3
Oats 1 oz. .	10·2	50	6·0	21·8
Potatoes 4 oz. .	10·7	54	7·3	14·6
Oats 2 oz. .	8·9	42	4·4	13·0
Potatoes 8 oz. .	10·2	44	6·1	6·6

It is clear that the substitution of potatoes for oats does not change the dry-matter requirement per 1 lb. live-weight increase to a very large extent. The potato-fed rabbits tend to eat more hay and less succulent food than those receiving oats.

Fertility.—There has always been doubt whether or not the use of potatoes affected the fertility of breeding rabbits. So far no evidence has been obtained to indicate that fertility is affected. The results obtained refer to the autumn months, the time of lowest fertility.

Two bucks which were reared on potatoes, hay, and green food only have been used:

♂ T 284 c mated 9 does: percentage fertile matings = 44·4.

♂ T 292 h mated 6 does: percentage fertile matings = 50.

The average percentage fertility of the corn-fed bucks over the same period was only 20 per cent.

Both of the above bucks were very young at the time of these trials.

Of the 18 potato-fed does that were mated in the autumn 11 kindled after the first mating.

These results, so far as they go, do indicate that fertility is not affected by potato-feeding.

Also, it has been shown that a doe reared on potatoes, roots, and hay alone will herself breed and rear a litter on this same ration. If mineral deficiency were caused by such a diet, a doe might prove fertile but be unable to lactate normally after kindling. As this has not occurred there is no reason for doubting that a diet of potatoes, roots, and hay is sufficient for breeding and rearing rabbits. Potato-feeding has been carried out at Cambridge on rabbits now for three generations without any untoward results being observed.

Summary and Conclusion

1. *Condition of the doe during lactation.*—Daily rations of 16 or 12 oz. of potatoes or 4 oz. of oats were equally good in maintaining the condition of does during lactation.

2. *Mortality-rate of the young.*—As judged by the survival of the young, potatoes proved to be a wholly satisfactory substitute for oats. The 16 and 12 oz. daily rations were most suitable; with the former litters of almost any size could be kept alive; with the latter the limitation in litter-size was high (7 or 8 young).

3. *Growth-rates of young up to 88 days.*—Young rabbits from does on the 16 oz. potato ration, grew as satisfactorily as those from does on the 'full-corn' ration. The 8 and 12 oz. daily rations gave poorer results, but were still practicable.

4. *Growth-rates of young from 88 days onwards.*—Young on potato rations compared favourably with those on oats; 8 oz. potatoes daily per head was the most suitable ration tried, but this could be halved if potatoes became scarce.

5. *Fertility.*—There is no evidence that fertility is in any way affected by potato-feeding.

These observations justify the conclusion that potatoes can be safely substituted for corn during any period of the rabbit's life. With the present war-time bran allowance potatoes can be used as a supplementary ration. However, if the need arose, by the cutting off of all cereal-food supplies to rabbit-keepers, the industry could still be carried on successfully provided a sufficient supply of potatoes was available.

Acknowledgements

Warm thanks are due to Miss Theresa Ashton of Girton College, whose care and attention to the live stock alone made these experiments possible.

The general design of the experiment as well as the major part of the results in the first section of this paper are due to Mr. K. E. Hunt, who was transferred to the Ministry of Food before the experiments were completed. Thanks are due to Mr. E. T. Halnan and Mr. M. S. Pease for helpful criticism and advice throughout the experiment, and to the latter for correcting the author's proofs.

(*Received February 2, 1942*)

A METHOD FOR FOLIAGE COMPARISONS IN FIELD EXPERIMENTS WITH *HEVEA*

W. B. HAINES

(*Dunlop Malayan Estates, Limited*)

WITH PLATE 5

IN dealing with field experiments with rubber trees, and particularly for old stands, visual inspection is apt to find the amount of foliage or shade to be the easiest criterion for judgement. Foliage is almost certain to give the first reaction to plot-treatments, and proper measurement of it would be of great utility in this crop-plant whose other characters change but slowly under change of environment. A method was sought which could be readily used by numbers of field assistants, and accordingly the writer developed the following technique from simple beginnings, through steps, using as aids, first the leaf-pattern cast on the ground by the midday sun and then leaf-canopy images formed by camera or mirror. The method, which involves marking by purely subjective judgement, is quite satisfactory, and can be recommended where other factors, such as leaf-colour, seem important enough to be brought into the judgement; but it provides no standard that is reproducible by different workers.

The basic conception has been to treat the picture of leaf against sky, when taking a view vertically from the ground, as a pattern in black and white, and to evaluate the proportion of black to total area in conveniently small sections, which are properly drawn samples from the areas available. If the foliage is very dense, leaving only pin-points of light, special standards must be set up, but it is usual for stands of trees under experiment to reveal a fair proportion of sky, and it is to such cases that the following descriptions specially apply. The requisite number of stations is properly assigned down the avenues of trees to give a satisfactory random sample of foliage. At each place a stance is taken for an approximately vertical view of the sky and foliage. A reflex camera can be used, but a simpler device (Fig. 1, Plate 5) developed for the purpose is a small mirror with a peep-hole attached by a cardboard flap which fixes the position of the eye at a convenient distance. The mirror is held nearly horizontally with the head bent well forward, aiming to get a vertical line of vision between mirror and tree top. On the mirror surface is pasted a grid in bright colour, dividing a field of 16° angle into $3 \times 3 = 9$ small squares. Each of these is awarded marks in units up to 10 for the proportion of sky occluded. Thus 0 signifies open sky, 5 is half-sky and half-leaf, and 10 is complete leaf with no sky visible. The highest possible score for a single station is then 90. The eye is easily trained to discriminate these ten values. The judgement should be firm and unworried by trifles, such as slight movement due to breezes or unsteadiness of hand, so that the marks are read off fluently with the full realization that if the effort is honest all small errors are

taken care of by the large number of readings averaged. As an aid in training, or if special standards be needed, pictorial standards can be drawn and placed on the mirror so as to match them alongside the image.

Various types of leaf-pattern arise according to the stature of the trees, leaf-clusters in special clones, and other variables; and the presence of branches obviously causes some slight disturbance. For the present purpose the leaf-canopy is regarded as knitted into a sufficiently consistent whole, all such differences being merged into the statistical treatment. Actually, reliable comparisons can be achieved even in young stands where the canopy has not entirely closed. Only two things have to be avoided: (1) very low hanging branches in the foreground produce such magnified effects that they must be side-stepped; and (2) distinct open disease-patches are also best missed out. Variation due to obliqueness of view is referred to later.

Either device, i.e. mirror or camera, is easily adapted by masks and shades to let a light-meter function in place of the eye, if an objective reading is thought preferable. But this introduces a new and very awkward source of variation, namely the large fluctuation in the light from the sky itself. Much ingenuity and elaboration would be needed to retain fixed standards and to prevent this new factor from greatly increasing the error of a test. Trials have been made, but it was found that considerably less information could be gleaned for a given amount of time spent when a photometer was used.

The choice of season is important when undertaking foliage measurements, for the onset of secondary wintering during operations can badly interfere with the results. In theory the method presents an excellent means of gauging the trend of vigour in a plantation by periodical readings, which would give early warning of a need for manuring. That is important because, with the slowness of bark-changes, deterioration may proceed very far if one waits for falling yields to force themselves on the attention. But the extreme sensitiveness of foliage to season makes it necessary to exercise the most critical care that a short-term change is not mistaken for a long-term trend. Time will be required to work out the seasonal changes by actual measurements and so to provide the proper background for closer recommendations.

The Problem of Scale

The ideal scale is one which would have a linear relationship to the total area of leaf. The score of marks on the above convention is very far from conforming to this requirement, because the efficiency of the leaves in earning marks is lowered to the extent that they overlap in the picture, and this must be much more in evidence at high scores than at low. It is therefore desirable to seek a formula for transformation. If we imagine the leaves gradually and uniformly building up by a reversal of autumnal fall, then an accession of a given number should at any stage occlude the same proportion of what sky still remains. This leads to the elementary law of light absorption, $I = I_o(1-e^{-kx})$, where x corresponds to leaf-number. This might be considered as roughly applying to the

less dense leaf-distributions, shall we say up to scores of half full marks. But at high marks this exponential curve cannot apply, for it moves off asymptotically to absurdly high values in complete neglect of the limitations to leaf-growth imposed by the dependence upon light. The transformation curve was therefore brought to a definite foliage-value at full marks, which could be used as a definite, if arbitrary, standard. Guidance in the selection of this value was found after consideration of many data, the curve being made to conform to a factor which would give approximately the same station variance to plots of good foliage as to plots of poor foliage. Table 1 is derived from such a curve, station scores being evaluated in terms of a percentage of the convenient empirical standard.

TABLE 1. *Transformation of Station Foliage Scores to a more Linear Scale expressed as Percentage of an Arbitrary Standard*

Score:	10	11	13	13	14	15	16	17	18	19	
Percentage of standard:	*4*	*4*	*4*	*5*	*5*	*6*	*7*	*7*	*8*	*8*	
	20	21	22	23	24	25	26	27	28	29	
	9	*9*	*10*	*10*	*11*	*11*	*12*	*13*	*13*	*14*	
	30	31	32	33	34	35	36	37	38	39	
	15	*15*	*16*	*17*	*17*	*18*	*19*	*20*	*20*	*21*	
	40	41	42	43	44	45	46	47	48	49	
	22	*23*	*23*	*24*	*25*	*26*	*27*	*27*	*28*	*29*	
	50	51	52	53	54	55	56	57	58	59	
	30	*31*	*32*	*33*	*34*	*35*	*36*	*37*	*38*	*39*	
	60	61	62	63	64	65	66	67	68	69	
	41	*42*	*43*	*44*	*45*	*47*	*48*	*49*	*51*	*52*	
	70	71	72	73	74	75	76	77	78	79	
	54	*55*	*57*	*58*	*60*	*62*	*64*	*66*	*68*	*70*	
	80	81	82	83	84	85	86	87	88	89	90
	72	*74*	*76*	*79*	*82*	*84*	*87*	*90*	*94*	*97*	*100*

The table is offered without any attempt to establish its validity academically, but in the belief that it does something to straighten out what would be a very obvious distortion if neglected. Each station score should be transformed before further building up one's statistics. Such a transformation cannot be expected to increase the significant conclusions deducible from a given set of readings, but it gives a more reliable background against which comparisons of data from all sources can be made.

Some Applications of the Technique

I. An example was afforded by a comparison between two sections of an experiment of the 27-plot design (factorial combinations of N, P, K at levels 0, 1, 2). One section had continuous annual manuring for 7 years; on the other manuring had been discontinued after the fifth application. The latter had, however, received a uniform dressing of phosphate for the benefit of the ground-cover about 6 weeks before the foliage measurements were taken. Phosphate had always proved to be the main deficiency. The summary of results for this factor, given in Table 2, shows that sub-plots of the section on which

phosphate applications had been interrupted gave a less marked response to phosphate.

TABLE 2. *Foliage as Percentage of an Arbitrary Standard, Clone G. 1, Eight Years from Budding*

Continuous manuring, 7 years		*Manuring discontinued after 5 years, but cover manured 6 weeks before measurement*	*Difference*
No phosphate	38·7	43·6	+4·9
Unit dressing	63·5	60·9	−2·6
Double „	68·0	61·5	−6·5
	±1·23		±2·5

II. In the next example long-established effects were dealt with. Measurements were made to compare foliage with girth as criteria of the poaching of manures across boundaries of experimental plots. The case chosen is medium-grade seedling rubber on a typical granite soil, planted 20 × 10 ft. in 1917. The plots had been under annual treatment for 10 years (1931–41). There was no digging for the purpose of isolating plots, though the root-systems had been to some extent broken up by silt-pitting about 1929, and the only provision at boundaries was a single guard-row of trees. Eight independent sites were afforded in the same experiment where manured plots and controls were contiguous, with rows parallel to the boundary 20 ft. apart. Nine successive rows were taken at each of these boundaries in such a way that No. 4 would be the guard-row, with No. 1 on the manured side. In each row about 6 trees were measured for girth, and 5 foliage stations taken in the avenues between. The average results (Table 3) show that trees have effectively poached on manures applied as far as 80 or 90 ft. away. It would

TABLE 3. *Poaching of Manures measured by Girth (cm.) and Foliage (per cent. of arbitrary standard) 20 ft. between Rows*

	Manured			*Guard*	*Unmanured*				
Row	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Girth* aver. (cm.)	117·7	114·2	117·1	110·6	103·7	101·4	98·5	97·9	94·9±2·78
Foliage, % of standard	62·6	55·7	50·3	46·8	37·9	27·6	21·2	20·2	±2·74

* Average girth at beginning of experiment may be taken as 86 cm.

be interesting to know whether this represents a limit, or whether further encroachment is still slowly going on. The valid control plots are now the cores left after discarding several rows from any part of the periphery in contact with a manured plot. The plots had originally 200 trees each, and it can be calculated that a square control plot surrounded by manured ones would now retain only 40 trees unbiased by stolen ad-

vantage. If one dimension should be less than 160 ft. the plot would have no representative trees left. Routine girth-measurements on the entire plots are available and give the following instructive comparison:

	Manured	*Control*	*Apparent effect*
	cm.	cm.	cm.
Unbiased trees in poaching test	116·0	94·9	21·1
All trees sampled equally (same plots)	111·1	102·2	8·9
Loss or gain by poaching	−4·9	+7·3	..

This is possibly rather an extreme case, as another site carrying smaller trees on a dense pea-laterite soil showed the poaching extending over only half the distance.

Foliage measurement has proved to be the more sensitive criterion, for whereas manuring has increased foliage threefold, it has increased the girth by only one-quarter. The ranges covered by the two measures assume much the same magnitude if girths are expressed in half centimetres (foliage range 42·4 units, girth 45·6 units), when the girth-error is more than double that of the foliage index; in other words, the foliage index has proved four times as accurate as girth when applied as a test of the same experimental material.

III. A complete analysis of a set of primary readings without any transformation of scale is instructive. The case chosen is a relatively uniform set of 27 experimental plots of Clone B.D. 5, divided into sections with continuous and interrupted manuring, as already described for Example 1. The number of unit readings was 9,720, made up of 27 full plots × 2 sections × 20 stations × 9 unit squares of grid. Table 4 gives the distributions of the unit readings and of the station scores. Both curves

TABLE 4. *Distribution Data of 9,720 Primary Readings (Unit Squares of Grid)*

	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
No. of trees	10	15	54	127	282	401	1,040	1,362	1,957	3,038	1,434
	Distribution of 1,080 station scores										
Score, units	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
Tens	..	..	..	..	..	..	..	..	..	..	
20	..	..	..	*1*	..	..	..	..	..	..	
30	..	..	..	*1*	..	..	..	*1*	..	..	
40	*1*	*1*	*1*	*1*	*5*	*1*	..	*5*	*3*	*5*	
50	*1*	*3*	*3*	*3*	*5*	*10*	*9*	*11*	*13*	*12*	
60	*15*	*19*	*29*	*33*	*36*	*32*	*41*	*33*	*39*	*42*	
70	*44*	*56*	*45*	*63*	*44*	*40*	*56*	*49*	*44*	*39*	
80	*38*	*37*	*31*	*26*	*20*	*10*	*8*	*8*	*5*	*1*	

are skew, but the distribution of station scores becomes symmetrical if transformed according to Table 1. Although the modal unit award is 9 marks out of 10 (that is, very near the maximum), the modal station score is 73, which corresponds to only 58 per cent. of the foliage standard

used. The analysis of variance, in the units of the primary awards, is given in Table 5. The differences between sub-plots gave a significant effect for phosphate in the sense described in Table 2. The main factors

TABLE 5. *Analysis of Variance*

	D.F.	*Sum sqs.*	*Mean sq.*
Full plots	26°	1,498	..
(15° for error)	..	..	21·9
Sections	1°	94	94·2
Sections × Full plots	26°	505	..
(15° for error)		..	14·8
Sampling error (stations within sub-plots 54 × 19)	1,026°	7,537	7·3
Position on grid	8°	272	34·0
Remainder error	8,632°	18,900	2·19 root mean sq. 1·48
Total	9,719°	28,806	

Standard deviation after deducting Sheppard's correction = 1·45.

showed small but highly significant positive effects for nitrogen (3·2 per cent. more than control), and phosphate (8·2 per cent.), with the two levels in each case almost identical. It is interesting to note the contrast between this very small effect of nitrogen on a young stand and the very large effects reported for old trees. The experiment proved an accurate one with a plot error of only 3·12 per cent. of the mean. The treatment-error variance is three times that for sampling (stations), from which it may be judged that a sampling of 20 stations in about 200 trees has been sufficiently intense to garner the available information. It is also indicated that the macrocosmic variance from station to station is significantly greater than the microcosmic variance of the nine contributory readings at a station: the span of the major natural field fluctuations is wider than can be taken in a single view.

It is noteworthy that the positions in the grid show significant differences (Table 6). The emergence of such a feature was not expected and came as a useful proof of the integrity of the observer. The readings in this particular case were taken with a reflex camera, which was set up on its stand (lens-axis vertical) always in the same orientation in the middle of the standard rectangles formed by the planting rows. The columns in the table read in the direction down an avenue 18 ft. wide, the planting

TABLE 6. *Positions in Grid averaged at 1,080 Stations, expressed as Differences from Grand Mean taken as 100*

						Totals
(1)	+2·86±·57	(2)	+2·48	(3)	+2·96	+8·30
(4)	−0·14	(5)	−0·85	(6)	−0·58	−1·57
(7)	−2·48	(8)	−2·85	(9)	−1·40	−6·37
Totals	+0·24		−1·22		+0·98	

points being 12 ft. apart down the rows. The foliage would be expected to be thinnest in the middle position (5) farthest from tree-boles, and the displacement of the lowest value to position (8) was found to be due to a camera maladjustment, the lens-axis being slightly raised relatively to the central point of the screen. Apart from a regular bias in the observer's judgement (which is unlikely to assume this form), the differences would be explained by (*a*) the real periodicity of leaf-density in relation to tree-position, and (*b*) the apparent increase in density as the line of vision declines from the vertical. Since the differences are much greater in the direction down the avenue than across it, we might deduce that the first explanation has some validity, in which case the technique has been proved sufficiently sensitive for a study of space utilization by trees in different geometrical systems of planting. Regarding (*b*), the smallness of the differences indicates that slight deviations from the proper line of sight, such as are unavoidable when using the hand mirror, are not likely to introduce large errors. Equally, it will usually be unimportant to relate the position of the stations exactly to that of the tree-boles.

IV. As an example of foliage effects in deteriorated stands the following is typical. The fields in question were planted in 1917 on previously cultivated land, and they deteriorated rapidly very soon after tapping began. Preliminary work had shown that nitrogenous manuring produced very good effects, and when a large area was being brought into manuring with sulphate of ammonia in 1936 an extensive new experiment was started to examine more closely the question of dosage. The design of seven treatments (Table 7) was arranged to give a minimum of poorly manured plots. In 1939 the plots were split to test the effect of a phosphatic dressing on one-half of each. Foliage measurements were made in January 1941 over one-third of the whole experiment, comprising 42 plots of single-task size (about 300 trees) as six randomized blocks covering two fields. Ten stations were taken in each plot. Table 7 summarizes the results for nitrogen treatments, and compares the yield and growth data for the previous year. The growth-rate

TABLE 7. *Foliage, Yield, and Growth Values in a Sulphate of Ammonia Experiment*

	Foliage in units, % of standard Jan. '41	*Yield 1940, lb./ task/ tapping*	*Growth-rate 1940 mm./yr.*
1. Control	12·9	6·64	9·6
2. 1½ lb. S/A. per tree annually for 5 years	31·2	7·71	16·5
3. 3 ,, ,, ,, ,,	40·0	9·96	23·3
4. 4½ ,, ,, ,, ,,	44·8	9·46	29·6
5. 4½ ,, S/A. annually for 3 years, then stopped	35·3	8·42	31·0
6. ,, ,, then 1½ lb. for 2 years	44·1	8·24	31·4
7. ,, ,, then 3 lb. for 2 years	44·8	9·12	30·4
	±2·25	±0·515	±2·28

is the girth-increment derived from successive measurements on the same sets of 40 trees per plot.

The low foliage-value of the control gives vivid proof of the poor character of the stand. The nitrogenous manuring increases both growth-rate and foliage by over three times, producing quite satisfactory levels when it is considered that the trees had previously suffered prolonged deterioration and die-back. In treatment No. 5 the stoppage of manuring for 2 years, after building up for 3 years, is showing a significant backward effect on foliage, but none can yet be proved for growth or yield. The relative utility of the three criteria for detecting differences may be assessed by considering the standard errors and the magnitudes of the effects: foliage proves at least seven times as useful as yield, in spite of the incomparably greater amount of work in accumulating yield-data, and more than twice as useful as girth-increment, in spite of the latter measurement being sampled more intensively (at 40 trees per plot in place of 10 stations for foliage). The foliage sampling error was $\pm 1{\cdot}57$, which compares with the experimental error of $\pm 2{\cdot}25$ to show a loss of information by incomplete sampling of some 47 per cent. The number of stations per plot could therefore in general be increased with advantage, and twenty has been adopted in practice, although in this experiment of very large responses an increase is not of great importance.

The phosphate effect on growth was $+2{\cdot}68$ mm./yr., which is significant, though so much smaller than that due to the nitrogen treatment. On foliage the total phosphate effect was negligibly small ($+0{\cdot}9$ per cent.), but the differences for this split gave a significant mean square for blocks, z value $= 0{\cdot}520$, when the value required in the 5 per cent. probability table is $0{\cdot}465$. This would indicate that although no consistent phosphate effect on foliage showed for whole fields, it might be worth while exploring further for one among the minor or small-scale site differences. The yield-data for the phosphate split were not available.

It may be pointed out that, although in a given stand of trees a fairly close relationship must exist between changes in foliage and vigour, and ultimately between these and yield, it must not be assumed too easily that foliage responses will be an unexceptional measure of potential yield responses. Other factors no doubt exist, physiologically irritating or stimulating on the one hand, or sedative or depressive on the other, which tend to affect yield through channels not intimately connected with the amount of leaf. It is hoped that the new tool which has been forged will assist investigation.

Summary. Foliage values in stands of rubber-trees are assessed by means of a simple viewing-device of mirror and grid, with a convention for awarding marks. In comparison with other direct criteria it is claimed that the method gives more speedy indications of tree reactions than anything hitherto generally used.

Acknowledgements are due to Dunlop Malayan Estates, Ltd, for permission to contribute this paper.

(*Received November 17, 1941.*)

FIG. 1. Mirror-device in detail and in use

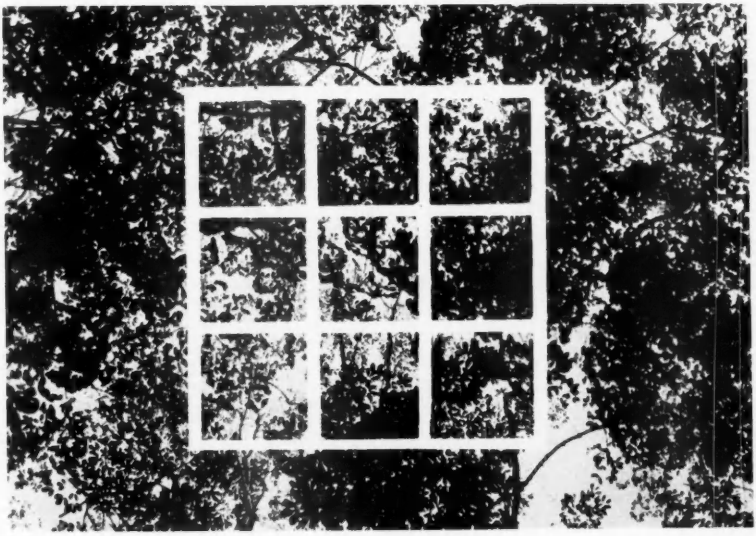


FIG. 2. Typical view of foliage in an old stand. This station reads : 6, 5, 3, 8, 4, 4, 6, 6, 6 = 48 marks out of 90, corresponding to 28 per cent. of the arbitrary standard of foliage set up for this work

A NEW SYSTEM OF GRASS-FALLOW STRIP-CROPPING FOR THE MAINTENANCE OF SOIL FERTILITY

A. J. KERR

(*Department of Agriculture, Uganda*)

Introduction.—In the literature of soil conservation prominence used to be given chiefly to the physical methods of controlling soil erosion, often to the exclusion of agricultural methods for maintaining soil fertility. It is, however, becoming increasingly evident that the application of physical methods for erosion-control is too frequently a case of 'closing the stable door after the horse has gone', and the importance of soil crumb-structure in its relation to water-absorption and soil fertility is gradually becoming more widely recognized.

Strip-cropping is one of the physical methods advocated for combating and controlling soil wash, but it is the object of this paper to show how it can be adapted to serve the more fundamental concept of maintaining the fertility of land cultivable under annual crops with particular reference to the elephant-grass (*Pennisetum purpureum*) areas of Buganda. The principle may, however, be of wider application not only in Africa but in other tropical and sub-tropical countries where circumstances do not favour mixed farming.

The system in brief is a basic rotation of accelerated shifting-cultivation applied as strip-cropping. It has been applied at the Kawanda and Bukalasa Agricultural Stations, and also, on a small scale, to peasant agriculture in Buganda with results that may be far-reaching.

Historical résumé.—When it is remembered that 'soil conservation' came to the fore when serious secondary troubles such as gulley and wind erosion became strikingly evident in countries where the primary principle of maintaining soil fertility had been neglected, it is understandable that the physical control of erosion first received attention.

Whilst the maintenance of soil fertility in tropical and sub-tropical countries is perhaps not directly comparable with that in temperate zones, nevertheless there may be a certain parallel in that 'prevention is better than cure', and it is significant that English farming has followed the dictum of keeping the land in good heart even to the extent of a compensation clause in tenants' agreements for dilapidations or improvements in this respect.

It is well to recall, also, that the African's experience of agriculture in his own country may be worthy of more than cursory examination. He well knows good land from bad, what crops will grow best and where, and, above all, the value of regenerated land and when it can no longer be profitably cultivated. An expression of this cumulative experience is perhaps to be found in the system of shifting-cultivation.

It is also common knowledge that certain tropical soils having an adequate mineral-content and an apparently satisfactory mechanical analysis can, nevertheless, be infertile. A field study often reveals that such soil does not readily absorb rainfall, whilst rough and ready experi-

ments can be made with it to demonstrate the same thing. For example, when water is sprayed on to a tilted box full of the soil, instead of absorbing the water readily its dusty surface pans into an impervious layer, with the result that the water runs off if there be the slightest slope, carrying away suspended soil particles with it. It is reasonable to expect plants to suffer from water-shortage and its attendant effects when growing on soil of this kind under tropical conditions, and the germination of cotton seed in it I have observed to be invariably poor. On the other hand, soil from regenerated land will absorb water copiously to a considerable depth.

The African peasant has long since appreciated this state of affairs instinctively, and though he has not understood the 'whys' and 'wherefores', his answer to it has been shifting-cultivation. This practice served its purpose until comparatively recent times, and it is only in the past 20 years or so that the old balance of cultivated to resting land has been upset in Buganda by the cultivation of economic crops on a large scale. In Mengo District, some 350,000 acres of cotton alone are planted annually, and over-cultivation with its attendant evils (loss of soil fertility, erosion, and finally movement of population) is already apparent in the more populous areas. *Mitala* surveys [1] give useful data on the subject. The proportion of rested to cultivated land in the more densely populated areas is sometimes barely adequate to ensure proper regeneration, even under an accelerated form of shifting-cultivation, and under the existing native practice of abandoning a plot (when its soil becomes worn out) to the natural ecological succession, a longer period is required for regeneration and the position is worsened. Under this practice a succession of annual weeds is usually followed by certain grasses and perennials which act as a nurse-crop for the seedling elephant grass, but the period required for this process, until a full cover of elephant grass is attained, is largely wasted from the point of view of regeneration.

Whatever the disadvantages of the system of shifting-cultivation, it has at least emphasized the importance of regeneration in the maintenance of soil fertility. This in turn has given the clue to a fundamental concept which Dr. W. S. Martin, Senior Chemist of the Uganda Department of Agriculture, was amongst the first, if not the first, to stress—the importance of crumb-structure in relation to soil fertility, and the value of regeneration in securing it. Amongst other authorities G. Milne, Soil Chemist, East African Agricultural Research Station, Amani [2, 3], and G. V. Jacks [4], deputy director of the Imperial Bureau of Soil Science, Rothamsted, have advocated the rejuvenation of soil under temporary leys. An article in the *East African Agricultural Journal* by G. W. Nye [5] describes the use of elephant grass in this connexion, and indicates how a speeded-up form of shifting-cultivation can be secured under Buganda conditions by planted elephant grass. When elephant-grass reeds are planted in shallow trenches 3 ft. apart in favourable weather, a full cover is obtained within a few months and satisfactory regeneration follows in 3 years or even less.

With this knowledge, an attempt was made to introduce to African peasants through the medium of cultivators' courses at the Bukalasa

Experiment Station, a 'six-course economic rotation' and an 'eight-course food-crop rotation', but it met with little success mainly owing to the complicated and inflexible nature of the rotations.

Since that time I have devised various systems which have been tested at prison farms, &c. All have included the basic rotation of 3 years' cultivation followed by 3 years' regeneration under planted elephant grass. The drawback of having one half of the land under cultivation for 3 years and the other half simultaneously resting is that the work of opening up the latter and laying down the former in the fourth year is prohibitive. It is preferable to rotate this work over a 6-year course by dividing the land into six plots. The three cultivated plots may be grouped together, preferably in the form of strips if the land is sloping, but in this case it is usually necessary to have bunds between them.

The Six-strip Alternating Grass-Fallow System

This is undoubtedly the most satisfactory system. Six strips are marked out across the slope and in the first year alternate strips are cultivated, the remainder rested. It is perhaps simpler to regard them as three pairs of strips, one strip in each pair for cultivation each year and the other resting. In the second year, to get into the rotation, the strips in the first pair are changed round; in the third year those in the second pair are changed round; and in the fourth year those in the third pair, as is shown in Fig. 1.

		Year															
		1		*2*		*3*		*4*		*5*		*6*		*7*		*8*		*9*		*10*	
Strip No. 1	1st pair	C		(R)		R		R		(C)		C			C		(R)		R		R
,, 2		R		(C)		C		C		(R)		R			R		(C)		C		C
,, 3	2nd pair	C		C		(R)		R		R		(C)			C		C		(R)		R
,, 4		R		R		(C)		C		C		(R)			R		R		(C)		C
,, 5	3rd pair	C		C		C		(R)		R		R			(C)		C		C		(R)
,, 6		R		R		R		(C)		C		C			(R)		R		R		(C)

(as in 1st year) (as in 2nd year) (as in 3rd year) (as in 4th year)

C = cultivated; R = resting. Brackets indicate a change-over.

FIG. 1. Scheme of alternating elephant grass with fallow.

It will be seen that each strip receives 3 years' cultivation followed by 3 years' resting, and that in any one year (having got into the rotation) one of the three cultivated strips is in its first year of cultivation, one in its second year, and the other in its third year, whilst the same applies to the three resting strips.

With this arrangement the soil crumb-structure and fertility in the Buganda elephant-grass area is maintained at a level sufficiently high to enable the soil to absorb its rainfall, and so make it unessential for strips to conform to the true contour even on the steepest cultivable slopes. Even if erosion occurs on the steeper slopes it is immaterial, because the resting strip below acts as a stop-wash. A further point is that, although

occasionally two cultivated strips fall together, e.g. in the second year, it is of little practical concern as it is only for one year in the cycle. The position is automatically remedied in the following year. Theoretically, the width should vary according to the degree of slope, but for application to African peasant conditions it is preferable to adopt a standard, which of course must be suitable for the steepest cultivable slope.

Application to Buganda conditions.—The system has already been applied at agricultural stations, to prison farms at certain county headquarters, and to a few schools and private holdings on a small scale. More recently, small administrative units known as *mitala* have been selected for improvement. This unit usually consists of a rather flattened hill about 1 square mile in area, often bounded by swampy land, and, in the more populous areas, generally containing a hundred or more holdings. In dealing with these units the first step is to seek the co-operation of landlord and tenants, and it has been found useful to form a small committee to act as a liaison body between departmental staff and the local interests concerned.

It is recognized that permanent crops, such as plantains and coffee, if properly tended as recommended locally, i.e. fully mulched, are not subject to erosion, and, in applying the alternating grass-fallow system to peasant holdings collectively, care is taken to emphasize that, apart from the actual demarcation of strips, the system relates only to land cultivable under annual crops. A most important point in introducing the system to peasant conditions is that the actual cropping within cultivated strips should be left solely to the discretion of the occupier.

Although at prison farms a rotation of crops has been superimposed on the basic rotation of cultivation and resting, in order to secure a steady supply of the required diet, this procedure would be too complicated for the successful introduction of the basic rotation to local conditions, quite apart from the facts that crop rotations appear to be of only secondary importance, and that the occupier, anyhow, knows his own particular requirements best.

The advisability of adopting for peasant conditions a standard width of strip which must be suitable for the steepest cultivable slope has already been indicated. It ensures a fairly constant ratio of cultivated to resting land at any given time and makes demarcation feasible for even unskilled staff. Whilst slopes steeper than 15 per cent. are frequently cultivated in some of the more populous areas of Buganda, most of the annual crops are cultivated on slopes below this range. On the basis of 9-ft. vertical falls between strips a 15 per cent. slope corresponds to a width of 20 yds., and, whilst from considerations of slope alone a width of 40 to 50 yds. would be permissible in some of the flatter country, narrowness is desirable to ensure that each holding contains replicated strips. On the other hand, strips must not be too narrow on account of border-effect. A standard width of from 20 to 25 yds. seems preferable on the whole.

As previously mentioned, it is not essential for the strips to conform to the true contour when the alternating grass-fallow system is employed;

in fact it may even be a disadvantage to demarcate strips on the contour with a specific vertical drop between them on account of the variation in width of strips entailed. For practicability, the method of demarcating a 'base-contour' at a convenient level to follow a true contour (but smoothed out to avoid sharp deviations) from which strips of a standard width can be demarcated, either for individual holdings or for adjacent holdings collectively, has much to commend it. It is preferable to work in units of 6 strips, numbered from 1 to 6. Each occupier can then be informed, or can easily ascertain, the identity of each strip included in his holding and which can be cultivated. This method, using units of 6 strips each 20 yds. wide and demarcated from a 'base-contour', has already been applied with satisfactory results.

It will be clear that the case outlined above relates to the more densely populated areas where most of the land is already occupied. The application of the alternating grass-fallow system to virgin land that is only in process of settlement is much simpler. First, it is required to decide upon the size of holding to support the family unit. It is generally accepted that the optimum size of holding for the average family unit in the Buganda elephant-grass areas is in the region of 12 acres, and, although in some of the densely populated areas the average size of holding is as low as 6 acres or even less, the minimum requirement can be taken as being 10 acres. Four acres are required for permanent crops and compound, and 3 acres for annual crops, thus entailing another 3 acres of fallow. To keep the holding compact it seems preferable to operate two units of 6 strips, each strip 20 yds. wide and 200 yds. long, i.e. the dimensions of the holding are 240 by 200 yds. Holdings of these dimensions can be laid out on either side of a contour path or road with the 12 strips running parallel to it marked with Dracaena cuttings on either side of the holding. It remains only for the landlord (or chief) to explain the numbering (from 1 to 6 in each of the two units) and in which strips cultivation of annual crops is permissible in any given year. It is immaterial where the compound and permanent crops are placed within the holding, the only check required being to see that no annual crops are planted within the resting strips. The scheme is represented diagrammatically in Fig. 2.

Advantages and disadvantages of the system.—(*a*) Soil fertility should be maintained at a high level indefinitely with resultant higher yields and profits. For instance, average yields of 1,000 lb. of cotton per acre should be within the bounds of possibility, as compared with present average yields of less than 500 lb. per acre. With labour costs but little increased, profits would be higher.

(*b*) The labour of clearing new land would be more evenly spread, and the general level of fertility would be kept constant within each unit of 6 strips, one strip being new land, one in its second year, and one in its third year of cultivation at any given time.

(*c*) Under the existing practice the tendency is for tenants to leave a holding which has become infertile owing to over-cultivation and occupy a more fertile holding in a less populous area. This practice has its drawbacks from both the landlords' and the tenants' point of view. The

landlord loses his *busulu* (rent)[1] and *nvujo* (tithe), the tenant his dwelling. The alternating grass-fallow system, by maintaining soil fertility, would counter this undesirable tendency.

(*d*) Regeneration under elephant grass, by improving crumb-structure, reduces soil-wash, and any unavoidable wash is adequately held by the adjacent resting strip without resort to costly bunds.

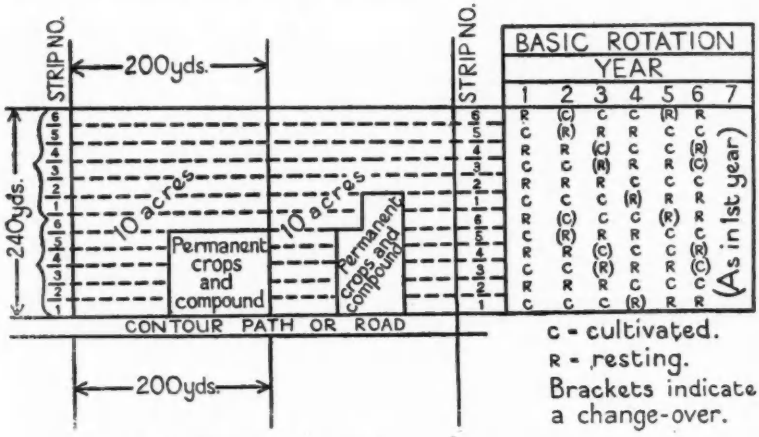


FIG. 2. Application of the alternating grass-fallow system to virgin land.

(*e*) It is not such a radical departure from existing native custom as might appear; witness the fact that some individuals have adopted it without any form of pressure being brought to bear.

(*f*) The tall elephant grass will act as a wind-break to the adjacent cultivated strip.

(*g*) To facilitate the opening up of resting strips it may be desirable to utilize the elephant grass for mulching nearby permanent crops, and then to use the strip as a temporary ley for grazing before it is cultivated. The cattle can be tethered if the strips are not fenced; but fencing is desirable for the permanent demarcation of strips. In this connexion it may be mentioned that a hedge-plant has been found having the necessary characteristics for the local purpose: fire- and stock-proof, easy to establish and tend, capable of surviving in competition with elephant grass whilst having negligible border-effect.

The one disadvantage of the system is that the planting of elephant grass in resting strips is a departure from native practice, and it is too early to gauge the reaction to this requirement. It is, however, not improbable that with careful propaganda it may be possible to finish the third year's cropping of a strip with ridge-planting, e.g. sweet potatoes, and split the ridges to bury elephant-grass reeds in the furrows. The

[1] On Crown Land a rent of Shs. 10/- per holding is charged but no tithe. On Native-owned Land, rent is Shs. 8/50 per holding, and a tithe of Shs. 4/- per acre of cotton and Shs. 4/- per acre of coffee is chargeable.

establishment of elephant grass from seed is another possibility, but it is not very promising.

Discussion

Although the system relates primarily to land cultivable under annual crops, its implications are not difficult to see. The use of the elephant grass from resting strips (prior to cultivation) for mulching, and the possible grazing or stall-feeding of cattle with consequential manuring, are the more obvious; and there seems no reason why units of 6 strips, not only of one *mutala* but of a whole district, should not conform to one definite schedule for the basic rotation.

Some readjustment of the land in individual holdings is not improbable, e.g. should a holding happen to fall all in one strip. In the closely populated areas, particularly near townships, the acreage under plantains is usually large in order to offset the low yields resulting from their establishment on worn-out land. This state of affairs, by reducing the area of land available for annual crops and regeneration, initiates a vicious circle; but the restoration of fertility to land cultivable under annual crops may lead to the transfer of permanent crops, thus releasing the old sites for regeneration under the alternating grass-fallow system.

It may happen that the system will not progress on the *mutala* concept but only as regards the individual holding. Whilst the former is preferable, it would at least not be a retrograde step if progress were made with the individual holding, which is the ultimate unit concerned.

If no progress is made at all, there is always resort to legal enforcement, as the question affects not only the individual but the community in posterity. If such resort should become necessary the following points would require to be covered:

(*a*) Minimum size of holding permissible.
(*b*) Prohibition of cultivation of annual crops except in strips of a stated width.
(*c*) For each strip cultivated under annual crops a corresponding strip to be rested.
(*d*) A strip cultivated under annual crops for 3 years to be planted with elephant grass.
(*e*) As regards re-allocation of plots to other tenants, land planted with elephant grass to be regarded as being under cultivation.

The last point has already been the subject of a ruling given by the Buganda Native Government for the guidance of chiefs.

On the other hand, should the system prove to be successful on a wide scale, a rotation of crops within the basic rotation could be advocated if found desirable. If an improvement in the basic rotation were discovered, the system could be readily adapted; for instance, should it be found that two years' resting with the application of manure is sufficient to maintain fertility, a change could be made to units of 5 strips with a 5-year rotation, each strip being cultivated for 3 years and rested for 2 years.

In conclusion, the significance of the system in relation to other areas of Uganda, and to other countries where the period required for

regeneration exceeds that during which the land can be profitably cultivated, is clear. There must be a point in this ratio when the land passes from an arable to a pastoral status.

REFERENCES

1. J. D. Tothill, A Report on Nineteen Surveys done in Small Agricultural Areas in Uganda with a View to ascertaining the Position with regard to Soil Deterioration. Government Printer, Entebbe, Uganda.
2. G. Milne, Essays in Applied Pedology II. East African Agric. J., 1938, **3**, 350–61.
3. ——, Kitivo Report 1937, paragraph 38 (Unpublished).
4. G. V. Jacks, Humus and the Farmer (Lecture to the Royal Society of Arts). Nature, 1941, **147**, 354.
5. G. W. Nye, Preliminary Notes on the Use of Elephant Grass as a Fallow Crop in Buganda. East African Agric. J., 1937, **3**, 186–90.

(*Received April 7, 1942*)

SOME OBSERVATIONS ON JASSID AT THE KENYA COAST

E. W. GADDUM

(*Agricultural Officer, Kenya*)

Introduction.—Up to the year 1936 cotton-growing on the Kenya coast was not attended by any abnormal loss in yield or quality due to pests and diseases. Yields in that year, however, were considerably smaller than usual and the exact cause of the abnormal loss was not apparent from general observations made in the field. Cotton yields in 1937 improved, but fell to a new level in 1938. In that year it was decided to begin an investigation into the cause or causes of abnormal crop losses; the work described in the following pages formed a part of that investigation. Although the results obtained do not support the view that jassid was the cause of abnormal crop losses, yet the information as to possible means of control which came to light during the investigation may well be of value if jassid attacks become more severe.

Jassid (*Empoasca facialis*) is a usual pest on cotton along the Kenya coast. In some seasons it has been recorded as a pest of some importance, but in other seasons it has not been numerous and probably has had no appreciable effect on yields. It has been recorded as plentiful in some years when good cotton yields have been obtained; for example, in 1935, when production on the coast reached its peak level of 4¾ million pounds of seed-cotton. It has also been plentiful in years when yields have been abnormally low, e.g. in 1938.

Density of the Jassid Population

It was obvious that the first necessity was the devising of a suitable technique for counting jassid in the field in order to record changes in jassid population. The method adopted was similar to that in use at the Cotton Experiment Station, Barberton, in 1937. A sample of individual plants is taken from a plot, and three leaves chosen at random from each plant are turned over and the jassid counted. The technique of random selection of the plants for counts is that described by Heath [1]. All the results given hereunder are recorded in terms of the mean number of jassid adults and nymphs counted per plant, i.e. from three leaves.

The counting of three leaves per plant does not, of course, give any absolute measure of the jassid population per unit of area or per plant. Plants having the same number of jassid per leaf may differ considerably in their total jassid populations because of differences in the number of leaves per plant. Other things being equal it is reasonable to assume that a large plant with a comparatively extensive leaf-surface is able to tolerate a larger jassid population than a smaller plant with a less extensive leaf-surface. It is therefore concluded that in any consideration of jassid populations in relation to their capacity to cause loss of crop it is best to record them in terms of jassid per unit of leaf-area and not in terms of jassid per plant or jassid per acre.

The technique adopted for the counts does not give a valid estimate of jassid per unit of leaf-area unless it can be assumed that all the leaves were the same average size. General observation suggests that differences in leaf-size might become a serious source of error under certain circumstances, e.g., in comparing counts from very young cotton with counts on mature cotton, or in comparing one variety with another of a widely different type, or in comparing the results of a wet year with those of a dry year. In the comparisons of jassid populations given below there were no apparent differences in leaf-size, and I therefore consider that this possible source of error does not materially affect the results obtained.

In 1938 only two counts were made. The first of these was made at a period which was judged to be about the peak of the infestation, the second shortly afterwards. The mean infestations were:

TABLE 1. *Jassid Population Densities, 1938*

	Jassid counted per plant	*Standard error*
Aug. 27	12·3	0·544
Sept. 6	5·0	0·224

In 1939 weekly counts were made in a combined cotton variety and interplanting trial. As will be explained presently, the practice of interplanting cotton with other crops may have an effect on the jassid population; consequently the figures given below represent the means of the counts made on five cotton varieties planted in pure stands only:

TABLE 2. *Jassid Population Densities, 1939*

Date	*Jassid counted per plant*
July 18	4·13
,, 25	5·52
Aug. 1	6·50
,, 8	4·87
,, 16	2·00
Sept. 15	0·53
Mean	3·925

Difference required for significance 2·4, $P = 0{\cdot}05$; 3·2, $P = 0{\cdot}01$.

It will be seen, therefore, that there was a significant rise in jassid population between July 18 and August 1. August 1 represented the peak of the infestation and thereafter the number of jassid decreased steadily. The period of heavy infestation lasted about 4 weeks, but a few jassid were to be found in the crop about a month after this period, as is shown by the count made on September 15.

Comparing the 1939 counts with those in 1938, it is apparent that the maximum jassid population per leaf was much lower in 1939 than in 1938.

In 1940 counts were made weekly on a ½-acre block in the centre of

the breeding-plots. The following mean population figures were obtained:

TABLE 3. *Jassid Population Densities, 1940*

Date	*Jassid counted per plant*
June 20	0·57
,, 27	0·59
July 4	0·35
,, 11	0·50
,, 18	1·27
,, 25	3·14
Aug. 1	2·30
,, 8	3·28
,, 15	7·07
,, 22	7·84
,, 29	9·65
Sept. 5	8·90
,, 12	9·65
,, 19	8·50
Oct. 3	1·05
,, 25	0·05
Mean	4·04

Difference required for significance 1·78, $P = 0{\cdot}05$; 2·34, $P = 0{\cdot}01$.

In 1940 there was a period of about five weeks in the early part of the season when jassid was present but not numerous. There was a significant increase between July 18 and 25, and in August there was a further large rise in population, reaching a maximum on August 29. This year, however, there was not a big fall in population directly after the maximum had been reached (as occurred in 1938 and 1939); the population continued at a high level for three weeks or more before any significant decrease was observed.

Differences in Jassid Population between Varieties

It has been our experience for some time that the cotton variety at present in cultivation at the coast, N. 17, is comparatively susceptible to jassid attack. This was one of the reasons for importing strains of jassid-resistant, U/4 type. That these imported strains are less attractive to jassid than N. 17 was shown in the 1938 counts (Table 4):

TABLE 4. *Jassid Counts on Cotton Varieties, 1938*

Mean No. of Jassid counted per plant

Date	*Varieties*				*Significant difference* $P = 0{\cdot}05$
	N. 17	*998*	*9243*	*955*	
Aug. 27	14·2	11·8	11·6	11·7	3·2
Sept. 6	6·9	4·1	4·5	4·4	1·3

Varietal differences were again found in the 1939 interplanting trial.

The following figures are the average of six counts made on the plots of non-interplanted cotton extending from July 18 to September 15:

TABLE 5. *Jassid Counts on Cotton Varieties, 1939*

Mean No. of Jassid counted per plant

Varieties					
698	*K. 71*	*K. 6208*	*K. 657*	*998/9243*	*Mean*
3·50	3·32	4·53	5·29	2·99	3·925

Significant difference: 1·15, $P = 0{\cdot}05$; 1·51, $P = 0{\cdot}01$.

Thus the variety 657 supported significantly more jassid than all the other varieties except 6208; and 6208 was significantly more attractive to jassid than K. 71 or the mixture 998/9243.

In 1940 weekly counts were kept on a block of ten varieties of cotton. The following average infestations were obtained over a series of sixteen counts extending from June 20 to October 25:

TABLE 6. *Jassid Counts on Cotton Varieties, 1940*

Variety	*Mean No. of jassid counted per plant*
511 C	2·19
A.F.C. 15	2·43
513 E	3·20
XA. 129	3·41
A.F.C. 26	3·55
G. 5·30	4·19
G. 5·123	4·22
7 L. 1	4·27
A.F.C. 6	6·15
XA. 1129	6·84
Mean	4·04

Significant difference: 1·40, $P = 0{\cdot}05$; 1·85, $P = 0{\cdot}01$.

Thus there is a considerable range of variation, which is further illustrated in Fig. 1, where the mean weekly jassid population of the variety with the lowest count, 511 C, is compared with the corresponding figures for XA. 1129, the variety with the highest average count. These two varieties happened to occupy adjacent plots and are therefore particularly suited for comparison.

During the past three years cotton on the coast has been observed to exhibit marked varietal differences in its attractiveness to jassid. In the past, selection work for jassid resistance has been a feature of our breeding policy at Kibarani, and although the present investigation suggests that jassid is not so important locally as it was at first thought to be, yet, in view of the severe losses that jassid has caused in South Africa and elsewhere, it is thought desirable to continue the resistant strains as a precautionary measure.

The Effect of Wind-protection on Jassid

During 1939 a cotton-yield trial of a factorial design was planted. It was designed to test the effect of interplanting maize, sorghum, and ground-nuts on a series of five cotton varieties. Jassid counts were made in this experiment and some results obtained from the plots of cotton planted in a pure stand have been given in Tables 2 and 5. The effect

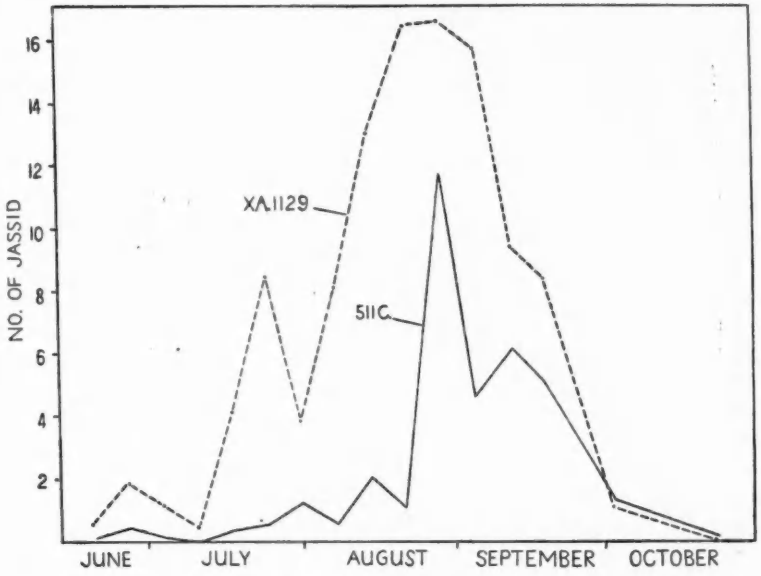


Fig. 1. Mean weekly jassid populations of cotton varieties 511 C and XA 1129.

of interplanting on jassid populations is given in the following table, each figure representing the mean of five varieties:

TABLE 7. *The Effect of Interplanting on Jassid Population*

Mean No. of Jassid counted per plant

Date	*Cotton and sorghum*	*Pure cotton*	*Cotton and ground-nuts*	*Pure cotton*	*Cotton and maize*	*Pure cotton*	*Mean of occasions*
July 18	2·15	4·20	5·20	5·25	0·50	2·95	3·37
,, 25	3·10	4·50	7·80	5·30	2·10	6·75	4·92
Aug. 1	8·15	5·30	7·85	5·35	1·60	8·85	6·18
,, 8	4·70	5·35	3·90	3·60	1·25	5·65	4·07
,, 16	1·60	2·15	1·95	2·00	1·60	1·85	1·86
Sept. 15	0·35	0·60	0·45	0·55	1·15	0·45	0·59
Mean of treatments	3·34	3·68	4·52	3·67	1·37	4·42	3·50

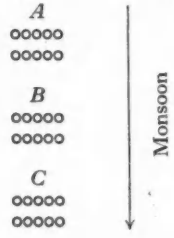
The mean of the pure cotton plots is 3·92. The difference required for significance between the means of interplanting treatments is 1·70 ($P = 0{\cdot}05$), and this figure also represents a significant difference between the means of occasions at $P = 0{\cdot}05$.

Thus cotton interplanted with maize has significantly fewer jassid than any of the other treatments. This treatment had the lowest count on all occasions except the last, when it had the most, probably because the other treatments had dried up more quickly, and were therefore less able to provide food for jassid; the cotton interplanted with maize had been shaded by the maize plants and therefore had not dried up to the same extent.

The reason for the reduced jassid population on cotton under maize was not known, but it was thought likely that the shade or the protection from wind afforded by the maize was concerned in it. If either of these factors was involved, then the provision of wind-protection or shade by other means than the interplanting of maize should have the same general effect. An opportunity of making an independent test of the effect of sheltering cotton from the wind was found in an experiment in which cotton had been planted in drums. In this experiment there were 30 cotton plants each growing in an oil drum; they were divided into 3 series of 10, each series being arranged in a double row of 5. As it happened, these drums had been arranged in such a way that the monsoon blew across the rows so that 5 plants in each double row were on the windward side and 5 on the leeward side.

The arrangement of the drums is illustrated below. These drums were the control part of a cage experiment designed to test the effect of waterlogging and insect pests on boll-disease. Treatment *A* received very heavy watering, treatment *B* was intermediate, and treatment *C* received a normal supply of water.

Arrangement of Drums in Cage Experiment



Jassid counts had been made on each plant separately over a series of weekly counts, and it seemed likely that, if jassid favoured exposed plants, there would be more jassid on the windward plants than on their leeward neighbours. Table 8 gives the relevant data.

The mean jassid population of each plant in the leeward rows was compared with the mean population of the plant in the corresponding drum of the windward row. The mean difference per plant, $2{\cdot}14 \pm 1{\cdot}22$, does not differ significantly from zero (for $P = 0{\cdot}05$), but is sufficiently

large to give some support to the hypothesis that the reason for the decreased jassid population in the cotton and maize plots of the earlier experiment is that the maize shelters the cotton from the wind.

TABLE 8. *Mean No. of Jassid counted per plant in the Drum Experiment, 1939*

Treatment	*Windward row*	*Leeward row*	*Difference*	*Treatment mean*
A	10·42	7·69	2·73	9·05
B	6·84	5·80	1·04	6·32
C	5·33	2·67	2·66	4·00
	7·53	5·39	2·14	6·46

It would be pleasant to be able to record that the cotton interplanted with maize had yielded better than the other treatment, in which jassid had been more abundant. Unfortunately this was not so. The maize was spaced 9 ft. between the rows, with two rows of cotton planted at $3 \times 1\frac{1}{2}$ ft. between each pair of maize rows. At this spacing the maize evidently had a definitely depressing effect on the cotton yields, and this outweighed any increased cotton yield which might have accrued through a decrease in jassid infestation. The question therefore arose: might not maize be planted in strips across a cotton shamba in such a way as to reduce jassid infestation without unduly affecting the cotton yields by competition?

To test the effectiveness of strips of maize as a means of reducing jassid, a small trial was planted in 1940; this consisted of a plot of cotton 33×33 ft. protected on the two windward sides by a strip of maize 12 ft. wide. Adjoining the protected plot on the exposed side was a control plot of unprotected cotton. This arrangement was replicated twice on two separate sites. Counts were made weekly on plants selected at random, the size of the sample being about 5 per cent. of the total number of plants in a plot. The results of a series of eleven counts are given below:

TABLE 9. *Jassid Counts on Wind-break Experiment, 1940*

Mean No. of Jassid counted per plant

Date	*Protected*	*Exposed*	*Occasion mean*
July 7	0·50	0·41	0·45
,, 25	0·23	0·68	0·45
Aug. 1	0·09	0·36	0·23
,, 8	0·14	0·41	0·27
,, 15	1·41	3·27	2·34
,, 22	0·82	1·91	1·36
,, 29	1·05	1·64	1·34
Sept. 5	0·73	2·23	1·48
,, 12	1·09	3·59	2·34
,, 19	0·64	3·09	1·86
Oct. 3	1·18	1·55	1·36
Mean	0·715	1·740	1·23

Significant difference between occasion means = 1·08 ($P = 0·85$).

The population on the two protected strips was substantially less than on the corresponding exposed strips, but there was insufficient replication for a convincing demonstration of the significance of this difference.

Losses caused by Jassid

In 1938 jassid damage to the cotton leaves began to appear towards the end of July. The infestation is believed to have reached its peak about August 27 and then to have fallen to about half the peak density on September 6 (see Table 1). By October 3 practically all jassid had left the crop. Crop losses were particularly severe in this year, and as the jassid attack had been heavier than usual, it was decided to make some field observations directed towards assessing the damage caused by this pest.

In the second half of September and the first week of October two series of counts were made. The area chosen for these counts was a randomized block, mulching experiments containing 9 replications of 2 treatments—mulched and control. Each plot was 1/20 acre, and all plots were planted with the same variety. As the counts revealed no difference between mulched and unmulched, no further mention need be made of this aspect of the counts.

In each of the 18 plots, 10 plants were chosen as having symptoms of severe jassid attack, and 10 other plants were chosen having their foliage as free as possible from jassid symptoms. Two series of counts were made, but the individual plants chosen for the second series were not the same as those taken in the first series.

The observations recorded were:

(1) *First Series.* All fallen bolls within a 9-in. radius of the main stem were collected. These were classified into: (*a*) those showing a boll-worm hole, and (*b*) those not showing a boll-worm hole.

(2) *Second Series.* In this count the number of healthy-looking, green bolls on each plant was recorded together with the number of dried-up or diseased bolls on the plant. An estimate of the number of fallen bolls was made by counting the scars on the fruiting spurs. It was not possible to be certain whether some scars represented fallen bolls or fallen leaves, but it was thought that the counts would be approximately correct and sufficiently accurate for comparing the two treatments. The same observer made the counts on all the treatments. There were, as before, 180 jassid-attacked plants and 180 jassid-free plants.

The following results were obtained from the first series:

(*a*) *Amount of boll-worm attack.*—An estimate of the severity of boll-worm attack on jassid-attacked plants as compared with jassid-free plants was made by comparing the numbers of shed bolls which had visible boll-worm holes.

Mean number of shed bolls per plant showing boll-worm holes:

Jassid-attacked . . .	5·89
Jassid-free	5·99

There was no evidence, therefore, to show that boll-worm had shown any preference for the greener foliage of the jassid-free plants, nor had

it concentrated on the jassid-attacked population. It should be mentioned that the commonest species of boll-worm at the coast is the Pink Boll-worm (*Gelechia gossypiella*); the spiny boll-worm (*Earias* sp.) also occurs but is not nearly so numerous.

(*b*) Mean number of shed bolls found per plant:

Jassid-attacked . . .	18·74
Jassid-free	18·02

Difference not significant.

It should be remembered that the figures given in sections (*a*) and (*b*) include only bolls which could be found at the time when the count was made. Bolls which had been shed earlier in the season may have rotted, and so no complete picture of shedding throughout the season is necessarily given by these counts.

The second series of counts gave the following results:

(*a*) Mean number of apparently healthy buds, flowers, and bolls per plant,

Jassid-attacked . . .	8·31
Jassid-free	18·08

Difference is significant ($P = 0{\cdot}001$).

(*b*) Mean number of fallen bolls plus shrivelled bolls on the plant,

Jassid-attacked . . .	28·64
Jassid-free	20·27

Difference is significant ($P = 0{\cdot}001$).

(*c*) Total number of buds and flowers produced,

Jassid-attacked . . .	36·95 per plant
Jassid-free	38·35 ,,

Difference not significant.
These figures are the sum of (*a*) and (*b*).

It therefore appears that although jassid had no noticeable effect on flower-production and probably none on boll-shedding, yet there were not so many healthy buds, flowers, and bolls on the jassid-attacked plants as on the jassid-free plants. The difference between the two classes in this respect was 9·77. On the other hand, there were 8·37 more shrivelled and fallen bolls per plant in the jassid-attacked class than in the jassid-free. The count of shed bolls made in the first series showed that shedding was the same for both classes, and it thus appears that the difference of 8·37 must be due to the greater number of shrivelled bolls in the jassid-attacked class. The term 'shrivelled bolls' refers to dried-up bolls remaining on the plant. Some bolls mummified when they were about the size of a pea, others grew larger and opened to reveal shrunken, dry, blackened contents.

The object of the above counts was to ascertain the type of damage done by jassid, and consequently plants showing the greatest possible amount of damage were selected for the jassid-attacked class. The results obtained from these counts, therefore, do not give a true picture of the state of affairs in the crop as a whole. The average amount of damage

sustained in the plots would have been much less than that recorded in these counts.

1939 Season

In 1939 the jassid infestation was less severe than in 1938, the highest recorded count averaging only 6·50 jassid per plant, as compared with 12·3 for the previous year. The infestation was between three and four weeks earlier.

As would be expected, the damage done by jassid appeared to be less severe than in 1938—in fact, no evidence can be produced to show that jassid caused any direct diminution in yield at all. For example, the cotton variety K. 657 having the highest jassid count (Table 5) did not yield less than the other varieties. Although treatment *A* of the drum experiment (Table 8) had significantly more jassid than *B* or *C*, it gave a higher yield than *B* and *C*. Likewise, the individual plant records showed no correlation between number of jassid and shedding, nor between jassid and numbers of shed bolls plus shrivelled bolls on the plant.

The figures in the 1938 count (second series) suggested that jassid attack was associated with an increased number of shrivelled bolls. Further evidence on this point was obtained in the drum experiment. Some results from this experiment are given in Table 10. The figures are given in terms of a single plant. There were 30 plants per treatment.

TABLE 10. *Some Results from the 1939 Drum Experiment: Mean Numbers per Plant*

	Outside cage	*Inside cage*
No. of flowers	40·8	43·0
No. of bolls shed	16·2	19·1
No. of shrivelled bolls remaining on plant	9·8	9·3
No. of bolls producing seed-cotton	14·8	14·6
Yield of seed-cotton (gm.)	40·0	42·1
Percentage staining	56·3	3·3

It will be seen that the results of the drum experiment confirm the 1938 counts as regards total flower-production and shedding—in neither year did jassid have any effect on these two factors. There appears, however, to be a difference in the effect of jassid on the numbers of shrivelled bolls remaining on the plant. In the 1938 counts the mean number of fallen bolls plus shrivelled bolls on the plant was found to be 28·64 for the jassid-attacked and 20·27 for the jassid-free; this difference was easily significant. The corresponding figures for the 1939 drum experiment were 26·0 for the jassid-attacked and 28·4 for the jassid-free.

In 1939 there was a remarkable difference in the amount of staining occurring inside and outside the cage. An exact analysis of the factors involved in causing the 56·3 per cent. staining outside the cage could not be made, but it is known that Cotton Stainers (*Dysdercus* spp.) had comparatively little to do with it, as most of the staining occurred in the early part of the season when stainers were absent. The Senior Plant Pathologist found that bolls shed in the early part of the season were

infected to a great extent with *Diplodia gossypina*, a fungus not hitherto recorded with certainty in the coast province.

The incidence of this fungus and of staining were at their greatest intensity in the early part of the season, both diminishing as the season advanced. The *Diplodia* was, towards the end of the season, replaced by *Nematospora*. It was thought that this association may not have been merely a chance one.

The appearance and departure of jassid from the experiment synchronized with that of *Diplodia gossypina*, but there was no direct evidence to suggest that they were vitally connected. Previous work on *Diplodia gossypina* in other countries suggests that it needs some wound in the boll as a means of ingress [2]. It is not known how *Diplodia* entered the boll. Boll-worms were present to some extent, but were not numerous; boll-worm and jassid were the only pests seen in the cotton at the time of the *Diplodia* infection.

1940 Season

The 1940 season was characterized by a very long period of jassid infestation (see Table 3). The highest recorded density was 9·65—higher than the 1939 peak, but not so high as in 1938. Boll-disease generally was greatly reduced; yields and percentage of clean cotton were correspondingly high in spite of fair damage to foliage by jassid.

A further cage experiment designed to test more specifically any possible relationship between jassid and boll-disease was carried out, but no connexion could be traced.

Further evidence on the possible influence of jassid on yield and quality came from the 1940 wind-break experiment (Table 9). The seed-cotton from these plots was weighed and graded. Although the jassid population on the protected treatment had averaged less than half that of the exposed, there was nothing to suggest that this had any effect on yield or quality. The results are given in Table 11.

TABLE 11. *Yields from 1940 Wind-break Experiment, expressed in pounds of Seed-cotton per acre*

	Protected		*Exposed*	
Expt. No.	*Yield*	*Percentage A quality*	*Yield*	*Percentage A quality*
1	1,006	79·3	1,270	83·6
2	1,041	73·0	935	66·8
Mean	1,024	76·1	1,102	76·5

In Table 6 a list of 10 varieties of cotton is given showing significant differences in attractiveness to jassid; there was, however, no indication of a correlation between yield and jassid attack.

It appears, therefore, that jassid may cause noticeable damage where plants are specially selected for showing jassid attack, and that jassid may be associated with the occurrence of *Diplodia* and staining. On the

other hand, cotton varieties attractive to jassid show no general tendency to yield less; the reduction in jassid population resulting from wind-protection by maize is not associated with increased yields; and the cage experiment in 1940 showed that there was no evidence of a direct relationship between jassid and boll-disease. It is noteworthy also that field observations confirm the view that bad jassid years are not necessarily years of low yield or high staining percentage.

Such evidence as has been collected, therefore, indicates that jassid has so far been a pest of minor importance as a direct source of crop loss. The possibility of jassid being concerned in the spread of boll-disease was investigated in 1940, and details will be published later; but it can be stated now that the results so far obtained do not support this hypothesis.

It therefore appears probable that the main cause of the heavy crop losses sustained in 1938 and 1939 must be sought elsewhere.

Summary

1. The technique employed for jassid counts is explained.

2. Some records of jassid populations in 1938–40 are given; the figures show the comparative severity and duration of the infestation for each of the seasons under review.

3. Significant differences between cotton varieties in their attractiveness to jassid were found in each season.

4. A graph (Fig. 1) showing the difference in jassid population between the most attractive and the least attractive variety in the 1940 counts illustrates the range of variation between varieties, and shows that the differences are well marked throughout the period of infestation.

5. Cotton interplanted with maize supported fewer jassid than cotton planted in a pure stand.

6. By comparing jassid populations on the windward sides of double rows of cotton with the populations on the leeward sides, it was found that jassid was more numerous on the exposed sides.

7. Planting of strips of maize as a wind-break reduced the jassid population of the protected cotton to less than half that of the control.

8. A field count designed to show the manner in which jassid causes losses in yield showed that jassid has apparently no effect on flower-production or boll-shedding. It did appear to be associated with an increase in the number of shrivelled bolls on the plant and a corresponding decrease in healthy buds, flowers, and bolls.

9. The drum experiment in 1939 confirmed the 1938 observations that jassid had no effect on flower-production and boll-shedding. In this experiment, however, jassid also had no effect on the number of shrivelled bolls on the plant or on the yield.

10. In the 1939 drum experiment jassid was associated with a large amount of staining and the appearance of *Diplodia gossypina* in the crop.

11. A cage experiment in 1940 did not support the view that this association was any more than a chance one.

12. During the period 1938–40 no association could be found between varietal attractiveness to jassid and yield.

13. Similarly, reduction of jassid population by wind-protection has not so far produced any evidence of increased yield.

14. Field observations over a number of years confirm the view that severe jassid attack is not always associated with low yields.

15. It is concluded that the main cause of the heavy crop losses in 1938 and 1939 was due to some cause other than jassid.

Acknowledgements

I gratefully acknowledge the assistance given by Mr. R. M. Nattrass, Senior Plant Pathologist, Nairobi, in examining and making cultures from a series of shed bolls; to Mr. A. P. G. Michelmore, Entomologist, for the identification of our local species of jassid; to Mr. R. W. Rayner, Plant Pathologist, Nairobi, who was responsible for much of the work on the 1940 cage experiment; and to the Statistical Department of Rothamsted Experimental Station for checking the statistics and for valuable criticism.

REFERENCES

1. O. V. S. Heath, Sampling and Growth Observations in Plant Development Studies on Cotton. Rept. Second Conf. Cotton-Growing Problems, July 1934 (Empire Cotton-growing Corporation).
2. C. W. Edgerton, The Rots of the Cotton Boll. Louisiana, 1912, Bull. No. 137.

(*Received June 30, 1941*)

DEVELOPMENT OF LIVE STOCK IN TANGANYIKA TERRITORY

V. SKELETAL DEVELOPMENT OF MASAI AND GRADE BLACK-HEADED PERSIAN SHEEP

M. H. FRENCH

(*Veterinary Department, Tanganyika Territory*)

A BRIEF description of Tanganyika sheep has already been given [1]; and this article contains a study of local sheep by the same method as that used by Hammond [2] for mutton sheep. Earlier observations [3] are supplemented and the same methods of preparing and examining the material, modelled on Hammond's work, have been retained.

Skeletal structures have in general an earlier phase of development than muscle or bony tissues, and are consequently less likely to be influenced by adverse nutritional conditions than the latter, because when the supply of nutrients is limited the tissues with the earliest phase of development have prior call on the nutrients available. For this reason skeletal development is being used more and more frequently to assess capabilities for producing mutton. The animals studied in this work were all fed as well as our present experience allows, and were certainly better fed than is normal in this Territory. The skeletal developments recorded may therefore be taken as representing the full potentialities of the animals for mutton production.

Weights and Proportions of the Skeleton

Table 1 contains the total skeletal weights of the sheep examined; Tables 2 and 3 give the average weights of the chief bones as percentages of the average cannon-bone weights. It is at once observed how small are the total skeletal weights of Tanganyika sheep when compared with those of improved British mutton breeds [2, 4]. The weights are comparable with those of the semi-wild breeds reported upon by Hammond [2]. Masai sheep have heavier skeletons than either the local long-tailed sheep [3] or $\frac{3}{4}$-grade Black-headed Persians (B.H.P.). This could have been expected from their greater stature.

If the different parts of the skeleton are expressed as a percentage of the whole it is seen that, as Hammond found for the Soay and Shetland breeds, the head forms a much greater proportion of the total than in improved breeds. However, in Tanganyika sheep the lumbar and sacral vertebrae and the long bones above the cannons in both fore and hind limbs form higher proportions of the total than in Hammond's semi-wild animals, possibly because the head forms a greater fraction of the latter skeletons. The ribs are the only part of the skeleton which shows a marked and consistent proportional increase with age. In grade B.H.P. the pelvic proportions increase with age, but their pelves are relatively smaller at one year than in Masai sheep.

Hammond showed that a better idea of relative developmental rates could be obtained by expressing the various skeletal parts as a percentage

TABLE 1. *Relative Proportions of the Skeletal Parts as a Percentage of the Whole*

Age in months	*Breed*	*No. of animals*	*Weight of skeleton in gm.*	*Head*	*Vertebrae*					*Ribs*	*Sternum*	*Pelvis*	*Scapula*	*Humerus*	*Radius-ulna*	*Metacarpal*	*Femur*	*Tibia-fibula*	*Metatarsal*
					Cervical	*Thoracic*	*Lumbar*	*Sacral*	*Caudal*										
6	Grade Black-headed Persians	2	821	21	6·8	6·5	4·5	1·4	0·4	6·8	1·4	3·5	1·3	3·4	2·8	1·8	4·0	3·7	1·8
8		2	1,015	26	6·5	5·8	4·2	1·4	0·3	6·5	1·4	3·2	1·4	3·4	2·7	1·7	4·0	3·7	1·7
10		1	1,437	26	6·8	4·1	4·0	1·2	0·3	8·1	1·4	3·3	1·3	3·1	2·4	1·6	3·6	3·3	1·7
12		2	1,791	22	6·5	6·2	4·7	1·1	0·4	6·8	1·2	3·4	1·4	3·0	2·5	1·5	3·6	3·4	1·5
14		1	1,702	25	7·5	6·0	4·4	1·4	0·4	8·0	1·5	4·4	1·6	3·1	2·4	1·6	4·1	3·6	1·8
16		2	1,639	25	7·5	7·3	4·9	1·6	0·4	9·6	2·1	5·0	1·7	3·5	2·7	1·7	4·7	4·4	1·8
18		1	1,847	26	7·7	6·6	4·4	1·7	0·3	11·1	2·3	5·3	1·8	3·7	3·2	1·6	4·3	4·2	1·7
28		4	2,409	23	7·3	6·3	4·7	1·4	0·5	10·2	1·9	4·5	1·7	3·1	2·6	1·3	3·8	3·4	1·4
12	Masai	1	2,278	21	7·4	6·3	4·6	1·6	0·3	10·2	1·8	5·2	1·8	3·1	2·8	1·6	3·6	3·3	1·7
14		1	2,511	23	6·8	5·5	4·4	1·6	0·4	10·6	1·7	5·0	1·7	2·9	2·6	1·5	3·7	3·2	1·6
16		1	2,583	22	6·9	5·8	4·4	1·8	0·5	9·4	1·6	5·3	1·7	3·3	2·7	1·6	4·1	3·6	1·7
18		1	2,819	26	7·0	6·2	4·7	1·7	0·4	9·3	1·6	5·0	1·5	3·1	2·6	1·5	3·8	3·5	1·6
20		1	3,057	21	6·8	6·7	4·8	1·7	0·3	9·3	1·5	4·8	1·7	3·3	2·8	1·6	3·9	3·6	1·6
28		1	3,327	20	6·8	6·7	5·0	1·8	0·4	10·5	1·5	4·9	1·8	3·0	2·6	1·5	4·0	3·8	1·6
18	Local fat-tailed sheep	1	2,199	26	6·5	6·2	5·4	1·8	0·9	9·3	1·3	4·1	1·7	3·0	2·5	1·5	3·6	3·5	1·6
24–30		2	2,526	24	7·6	7·0	5·1	1·6	0·6	10·6	1·6	4·7	1·7	3·0	2·5	1·2	3·7	3·3	1·4
60		1	2,778	23	8·6	7·1	5·2	2·0	0·7	11·3	1·8	4·4	1·8	2·6	2·2	1·2	3·2	2·9	1·2

of the cannon bones. The cannons are well developed at birth and Hammond states that they 'grow at a slower rate than any other part of the skeleton, with the exception of the bones of the foot'. Instead of using other long bones of the limbs, which are also relatively well developed at birth but have greater post-natal growth, Hammond gives the following additional reasons for using the cannons: (1) They are easily cleaned; (2) they are four in number and can be averaged; (3) they can be obtained without cutting up the carcass; and (4) they provide a good measure of the total skeleton.

TABLE 2. *Average Weights of the Bones as Percentages of the Average Cannon-bone Weight: Grade Black-headed Persian Sheep*

Age in months	6	8	10	12	14	16	18	28
No. of animals	2	2	1	2	1	2	1	4
	%	%	%	%	%	%	%	%
Skull	820	1,153	1,238	1,132	1,147	1,083	1,157	1,325
Lower jaw	340	400	366	377	365	345	436	431
Scapula	73	82	81	94	95	97	108	131
Humerus	187	200	187	204	186	197	226	234
Radius-ulna	153	165	149	170	140	155	193	197
Metacarpal	100	100	98	98	95	97	98	97
Femur	220	241	221	245	242	266	262	284
Tibia-fibula	200	224	204	226	214	248	249	256
Metatarsal	100	100	102	102	105	103	102	103
Pelvis	193	188	204	226	263	283	321	341
Ribs	373	388	498	498	477	541	669	766
Sternum	80	82	85	79	91	117	138	141
Costal cartilages	113	112	98	98	112	138	144	141
Vertebrae:								
Cervical	373	388	417	445	446	424	469	547
Thoracic	353	347	302	419	358	410	397	475
Lumbar	247	253	243	317	263	276	269	350
Sacral	80	82	72	79	81	93	102	103
Caudal	20	18	17	26	21	21	20	34
Av. cannon-bone weight (gm.)	15·0	17·0	23·5	26·5	28·5	29·0	30·1	32·0

Cannon bones.—The cannons in Masai sheep weigh about 1·5 times those in grade B.H.P. of the same age. Whilst the latter are similar in weight to Hammond's semi-wild types, the local sheep have cannon weights far below those of improved mutton breeds.

Long bones of the leg and shoulder.—In every case the actual weights of the long bones are heavier in Masai than in B.H.P. sheep but, whilst the proportional development is of the same order in both types, the B.H.P. bones tend to be slightly heavier relative to the average cannon weights. Compared with improved mutton breeds the local sheep have leg and shoulder bones which are much lighter actually and relative to their average cannon weights. The B.H.P. weights compare with Hammond's for a Shetland ram but, with the exception of the radius-ulna and the tibia-fibula, the B.H.P. bones are less well developed

relative to the cannon weights. In other words, the later developing limb bones (humerus, scapula, and femur) around which the greatest muscular growth is made, are less well developed in the local than in improved mutton animals.

TABLE 3. *Average Weights of the Bones as Percentages of the Average Cannon-bone Weight: Masai Sheep*

Age in months	*12*	*14*	*16*	*18*	*20*	*28*
Animal	*No. 29*	*No. 25*	*No. 36*	*No. 23*	*No. 33*	*No. 72*
	%	%	%	%	%	%
Skull	943	1,141	998	1,093	1,155	1,135
Lower jaw	335	346	300	382	345	367
Scapula	108	108	102	100	106	122
Humerus	189	187	198	198	208	198
Radius-ulna	173	167	165	168	173	169
Metacarpal	97	97	98	98	100	98
Femur	224	238	249	245	241	265
Tibia-fibula	205	208	219	227	227	251
Metatarsal	103	103	102	102	100	102
Pelvis	322	321	319	322	300	321
Ribs	627	682	563	595	582	682
Sternum	108	110	95	100	92	100
Costal cartilages	116	118	112	120	114	122
Vertebrae: Cervical	457	436	416	445	422	441
„ Thoracic	387	351	347	395	418	437
„ Lumbar	281	282	265	298	300	321
„ Sacral	100	103	109	111	106	122
„ Caudal	16	23	30	27	18	24
Average cannon-bone weight (gm.)	37·0	39·0	43·0	44·0	49·0	51·0

Head bones.—The skull and lower jaw are heavier in Masai than B.H.P. sheep, but all the present weights are below those of British breeds. The presence or absence of horns affects the weight and proportional development of the skull. Allowing for this, the weight actually, and relative to the average cannon weight, increases with age, but the rate of increase falls off earlier in the Masai than in the B.H.P. sheep. Relative to the cannons the skull is proportionally the same size in the local and improved British breeds, but the lower jaw, particularly in the B.H.P., is proportionately heavier in the local animals.

Vertebral column.—The weights of the different parts of the vertebral column are heavier in Masai than in B.H.P. sheep, even for the caudal vertebrae, though the Masai have much shorter tails with fewer vertebrae. Relative to the average cannon weight, the B.H.P. usually have greater vertebral weights than the Masai, except in the sacral region. All weights and proportional developments are smaller in the local than in British improved breeds, and compare with those of semi-wild types. Hammond found that 'on the whole the thoracic vertebrae show the smallest rate of post-natal growth', but the present figures do not agree with this. If we compare the proportional development of the later maturing portions (lumbar and sacral vertebrae) with British breeds, we

see that the local sheep have only half the relative development in those regions that characterizes improved mutton breeds. Since the highest priced and most valuable joints come from these areas, the poor skeletal development indicates how inferior local sheep are for mutton production. From the data available there appears to be no reason for thinking that the introduction of B.H.P. blood into the indigenous sheep has had any beneficial influence.

Ribs and sternum.—In weight and proportional development the Masai have much heavier ribs than the B.H.P. but, whilst the weights of the sternum are heavier in Masai, the proportions relative to the cannons are greater in B.H.P. sheep. The weights and proportions are all much below those of improved breeds.

Pelvis.—The pelvic weight is greater in Masai than in B.H.P. sheep, and the same applies to the weight relative to the average cannon weight. Whereas the proportional development increases steadily from 6 to 28 months in the B.H.P., it remains constant in Masai sheep from the 12th month. This earlier development of the pelvis in Masai sheep may be correlated with their greater size at birth. Compared with improved mutton sheep, the pelvic weights and percentages of local sheep are very small.

Linear Development of the Skeleton

Skull.—Length of skull tends to be slightly longer in Masai than in B.H.P. sheep. In depth of cranium and width between the eyes the two types show similar proportions. When compared with improved mutton breeds the local sheep have shorter skulls, but the most striking difference is the much shallower and narrower head. The local sheep thus have heads more similar to the Merino than to either the semi-wild or improved British breeds. Changes with age in the skull proportions in Table 4 support Hammond's findings that as the head develops there is 'a greater proportional growth in length than in width between the eyes or in depth of cranium'. Nathusius, quoted by Hammond, found that early maturing breeds have short broad heads and late maturing ones long narrow skulls.

Cervical vertebrae.—The average lengths of Nos. 3–7 cervical vertebral bodies are very similar in Masai and B.H.P. sheep, as are also the proportional transverse measurements of the atlas. The B.H.P., however, show slightly greater development of the transverse processes of the axis bone and Nos. 3–7 vertebrae. Except for the proportional transverse development of the axis bone, the average vertebral body-lengths and their transverse processes are smaller than in improved mutton sheep but compare well with those of semi-wild types. This series of measurements confirms Hammond's finding that, with age, the transverse process of the width shows a greater growth-rate than the vertebral body-length.

Thoracic vertebrae.—The thoracic vertebral body-length, and the relative proportions of the vertebral body-depth and of the length of the spinous process are very similar in Masai and B.H.P. sheep. Direct comparison with Hammond's figures is not possible, because he gives

values only for the first six thoracic vertebrae. Hammond found that for Suffolk rams the vertebral body-depth decreases in proportion to its length up to 5 months old, but after this age thickness-growth proceeds faster than length-growth. In the present study with unimproved, slow maturing, fat-tailed sheep, the point at which thickness-growth exceeds length-growth is not reached until about 14 months old. This applies to both Masai and grade B.H.P. sheep. Similarly with the relative proportions of the spinous process, Hammond found a slight decrease soon after birth owing to the more rapid growth in vertebral body-length, but later the proportions of the spinous process increased with age. Again, the point of minimum proportions in the present study is about 14 months.

TABLE 4. *Linear Dimensions of the Skull*

				Expressed as per cent. of skull-length		
					Width of eyes	
Breed	*No. of animals*	*Age in months*	*Length of skull* (mm.)	*Depth of cranium*	*Outside top of eye-orbit*	*Inside bottom of eye-orbit*
Grade Persians	2	6	156	34·9	55·4	36·5
	2	8	161	34·8	55·3	36·0
	1	10	180	31·7	53·3	34·5
	2	12	199	30·0	49·9	36·5
	1	14	207	31·4	49·3	35·8
	2	16	196	33·2	51·3	38·3
	1	18	205	31·7	51·2	37·1
	4	28	209	31·6	52·0	37·0
Masai	1	12	187	30·2	51·3	34·2
	1	14	190	32·0	51·6	36·1
	1	16	197	33·5	52·3	37·6
	1	18	206	32·5	51·0	36·9
	1	20	226	29·6	49·8	34·3
	1	28	238	29·8	49·6	34·8

Lumbar vertebrae.—The two types of sheep in this study have similar vertebral body-lengths, widths, and depths; the transverse-process lengths are also similar but the Masai has slightly longer spines. Hammond tabulates only the values of the 3rd, 4th, and 5th vertebrae, but the figures in Table 5 agree with his data that length-growth is greater than either the growth in width or depth of the vertebral body, and that the width of the transverse process and the height of the spinous process grow at greater rates than the vertebral body-length. In the local sheep vertebral body-lengths are not only smaller than in improved mutton sheep, but when compared with vertebral body-length, the growth in width and depth of vertebral bodies as well as the width of the transverse process are all inhibited more than in improved breeds.

Ribs and sternum.—Masai sheep have longer ribs than B.H.P., but have similar proportional widths and spring. Compared with improved breeds the local sheep have very much narrower ribs, which are also shorter and less well sprung. The age-changes for the local sheep agree with Hammond's data for improved types, namely a great increase in

TABLE 5. *Average Linear Dimensions of the Vertebrae*

Breed	No. of animals	Age in months	Cervical vertebrae				Thoracic vertebrae			Lumbar vertebrae				
			Average length of Nos. 3–7 (mm.)	Transverse process as per cent. of vertebral body-length			Average length of vertebral bodies (mm.)	Per cent. of vertebral body-length		Average length of vertebral bodies (mm.)	Per cent. of vertebral body-length			
				Atlas	Axis	Nos. 3–7		Depth of average vertebral body	Length of average spinous process		Width of average vertebral body	Depth of average vertebral body	Height of average spinous process	Length of average transverse process
¾-grade Persians	2	6	19	263	98	149	15	70	234	20	80	54	66	264
	2	8	23	254	99	158	17	65	250	22	76	49	74	277
	1	10	27	260	100	161	18	61	232	26	71	46	74	311
	1	12	26	241	103	164	18	62	241	25	72	48	77	290
	1	14	27	236	100	159	20	60	232	26	72	46	78	304
	2	16	26	232	101	168	19	62	255	25	77	47	77	296
	1	18	27	243	102	170	19	64	265	28	65	52	75	300
	4	28	29	240	106	185	21	68	271	28	71	52	81	309
Masai	1	12	24	245	87	139	19	67	242	26	71	47	74	308
	1	14	28	244	95	152	20	61	225	29	66	44	77	299
	1	16	31	241	102	158	20	63	247	26	76	53	83	306
	1	18	30	244	98	165	20	68	253	26	78	56	88	330
	1	20	29	243	98	163	21	70	278	27	81	57	86	307
	1	28	31	251	98	167	23	68	274	31	69	47	95	313

rib-length with only small proportional increases in width and maximum spring. The local animals compare with Hammond's semi-wild types.

The Masai has a longer sternum than B.H.P. sheep, but the proportional width is the same in both. Both length and maximum width resemble the semi-wild types and are much smaller than in improved breeds. As found by Hammond, Table 6 suggests that, with age, the maximum width increases slightly in proportion to the length.

Pelvis.—Masai sheep have slightly longer pelves than B.H.P., but both breeds have the same proportional width. The length and width are much less than in improved breeds; the length is about the same as in Hammond's semi-wild breeds, but the relative width is smaller. The local sheep have the same relatively narrow pelvis, as is found in the Merino, but the length in the latter is longer (Table 7).

Scapula.—In Masai sheep the scapula is both longer and wider than in B.H.P., but the ratio of the width below the spine to the width above it is about the same for both breeds. When compared with improved mutton breeds the scapula is shorter and very much narrower in local sheep; it is even narrower than in the Merino, and similar to that in Hammond's semi-wild breeds. As found by him, the width increases at a greater rate with age than does the length. Also, the width under the spine grows faster with age than the width above the spine. The proportional widths of these two parts is the same as in unimproved British sheep.

Humerus.—The humerus is longer and has a slightly greater relative thickness in Masai than in B.H.P. Hammond shows that improvement of sheep for mutton is accompanied by a greater increase in bone-thickness than in length. As would therefore be expected, in the local sheep the humerus is relatively smaller in circumference than in improved types; it is as slender as that found in semi-wild types by Hammond.

Radius-ulna.—This bone is longer in Masai, but its relative circumference is not very different from that of the B.H.P. grades. Unlike most other bones, the radius-ulna is as long as in improved mutton breeds, but it is considerably more slender. It has even a smaller relative circumference than in Hammond's semi-wild types. In the present series there does not appear to be any increased thickness-growth with age as compared with length-growth.

Metacarpals.—The Masai have the longer fore-cannons, but the circumference relative to the length is about the same as for the B.H.P. The local sheep have longer and more slender fore-cannons than any of those examined by Hammond, or Pálsson [4].

Femur.—The femur is longer and relatively rather thicker in Masai than in B.H.P. sheep. Compared with improved British breeds the local sheep have shorter and much more slender femurs. The B.H.P. femurs compare in length with the Shetland, and the Masai with the Merino, but in both cases the local sheep have less thickened bones. With improved breeds the relative circumference increases faster than length from about the 3rd to 5th month, but in local sheep this does not occur until about the 10th month.

TABLE 6. *Average Linear Dimensions of the Ribs and Sternum*

Breed	No. of animals	Age in months	Ribs 1 to 5			Ribs 6 to 8			Ribs 9 to 13			Sternum	
			Average length (mm.)	As per cent. of length		Average length (mm.)	As per cent. of length		Average length (mm.)	As per cent. of length		Length (mm.)	Maximum width as per cent. of length
				Spring	Maximum width		Spring	Maximum width		Spring	Maximum width		
Grade Persians	2	6	104	14·0	10·4	134	19·9	7·4	109	19·9	5·0	105	22·7
	2	8	122	15·9	9·7	160	20·2	6·8	130	22·4	4·8	143	22·8
	1	10	133	15·3	9·2	185	21·2	6·8	150	22·4	4·6	152	23·0
	2	12	134	16·2	10·7	176	22·5	7·6	150	20·3	4·6	145	23·2
	1	14	128	16·3	10·2	188	23·1	6·2	161	21·8	4·8	152	23·0
	2	16	131	15·2	10·3	170	21·3	6·6	132	19·9	5·0	144	24·7
	1	18	141	15·6	10·3	180	21·3	7·1	162	21·0	5·3	146	23·6
	4	28	152	16·0	10·0	195	23·1	7·2	159	22·0	5·1	158	23·4
Masai	1	12	127	16·0	10·8	166	21·3	7·0	142	19·7	5·3	145	20·3
	1	14	139	15·3	11·0	187	20·9	7·4	148	20·9	4·9	151	22·8
	1	16	140	15·3	10·6	191	20·0	7·7	148	19·8	5·3	156	23·7
	1	18	145	15·8	9·7	181	21·1	7·3	157	24·8	5·1	154	23·5
	1	20	158	15·5	9·9	211	21·0	7·6	152	22·5	5·1	163	23·3
	1	28	164	16·4	11·0	216	22·9	8·4	180	23·4	5·3	169	24·9

Tibia-fibula.—This bone is longer in Masai sheep, and its relative circumference is slightly greater than in B.H.P. Like the radius-ulna, the tibia-fibula is as long as in improved mutton breeds but considerably thinner. The B.H.P. length compares with that in Hammond's semi-wild sheep, and both local types have a thinness of shaft like that of the semi-wild types (Table 9).

TABLE 7. *Average Linear Dimensions of the Pelves*

Breed	*No. of animals*	*Age in months*	*Length* (mm.)	*Width as per cent. of length*
Grade Persians	2	6	127	27·3
	2	8	135	27·9
	1	10	166	26·5
	2	12	163	26·9
	1	14	162	26·7
	2	16	164	26·6
	1	18	171	26·5
	4	28	182	26·0
Masai	1	12	161	26·4
	1	14	173	26·5
	1	16	180	26·9
	1	18	182	27·2
	1	20	185	27·0
	1	28	202	26·0

Metatarsals.—As with the fore-cannons, the hind-cannons are longer and more slender than in improved British sheep. The hind-cannons are longer and relatively smaller in circumference than the fores in both local types, but the Masai has longer bones than B.H.P. grades.

TABLE 9. *Average Linear Dimensions of the Chief Bones of the Leg*

			Femur		*Tibia-fibula*		*Metatarsal*	
Breed	*No. of animals*	*Age in months*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*
Grade Persians	2	6	130	25·4	162	18·7	117	22·1
	2	8	149	25·3	188	18·7	132	22·0
	1	10	169	25·2	212	18·9	144	24·9
	2	12	167	25·8	207	20·2	141	25·6
	1	14	177	25·4	211	19·9	145	26·3
	2	16	162	26·9	200	20·2	141	25·6
	1	18	163	27·6	195	20·5	149	27·9
	4	28	183	28·6	214	21·3	152	28·6
Masai	1	12	155	26·6	189	21·0	130	26·0
	1	14	179	27·9	209	21·3	143	27·9
	1	16	186	28·7	203	22·9	146	28·3
	1	18	176	28·9	214	22·5	145	26·9
	1	20	187	30·0	238	22·7	157	25·7
	1	28	199	30·2	248	22·2	162	27·2

In Table 10 are given the linear and weight relationships of the limb bones expressed as a percentage of the cannon bone. It is seen that the relative lengths of the upper limb bones are the same for both Masai and

TABLE 8. *Average Linear Dimensions of the Chief Bones of the Shoulder*

			Scapula			*Humerus*		*Radius-ulna*		*Metacarpal*	
Breed	*No. of animals*	*Age in months*	*Length* (mm.)	*Width as per cent. of length*	*Width under spine as per cent. of width above*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*	*Length* (mm.)	*Circumference as per cent. of length*
Grade Persians	2	6	107	52·5	268	109	31·5	154	21·2	113	26·6
	2	8	123	49·0	339	122	32·9	171	20·5	123	27·2
	1	10	139	55·8	344	139	33·5	202	20·5	135	28·2
	2	12	139	56·1	352	138	34·1	191	20·9	131	28·6
	1	14	140	56·4	361	142	35·3	207	21·5	136	28·7
	2	16	140	57·9	377	142	36·1	196	21·5	134	30·0
	1	18	141	56·0	353	142	34·1	199	20·9	133	30·4
	4	28	150	57·8	360	151	34·1	225	20·7	139	30·4
Masai	1	12	132	61·3	273	129	33·6	176	22·3	123	29·0
	1	14	140	61·4	296	146	33·3	201	22·4	142	29·9
	1	16	142	62·6	318	147	33·7	206	22·9	146	29·7
	1	18	142	62·1	325	156	37·3	216	21·9	154	30·2
	1	20	162	60·3	350	156	38·5	220	22·1	154	31·2
	1	28	165	61·8	390	166	38·7	232	22·0	154	32·0

1938-39

M

TABLE 10. *Linear and Weight Relationships of Shoulder and Leg Bones*

			Shoulder								*Leg*					
				As per cent. of Metacarpal length				*As per cent. of Metacarpal weight*				*As per cent. of Metatarsal length*			*As per cent. of Metatarsal weight*	
Breed	*No. of animals*	*Age in months*	*Metacarpal length* (mm.)	*Scapula length*	*Humerus length*	*Radius-ulna length*	*Metacarpal weight* (gm.)	*Scapula weight*	*Humerus weight*	*Radius-ulna weight*	*Metatarsal length* (mm.)	*Femur length*	*Tibia-fibula length*	*Metatarsal weight* (gm.)	*Femur weight*	*Tibia-fibula weight*
¾-grade	2	6	113	95	96	136	15	73	187	153	117	111	138	15	220	200
Persians	2	8	123	100	99	139	17	82	200	165	132	113	142	17	241	224
	1	10	135	103	103	150	23	83	191	152	144	117	147	24	217	200
	2	12	131	106	105	146	26	96	208	173	141	118	147	27	241	222
	1	14	136	103	104	152	27	100	196	148	145	122	146	30	230	203
	2	16	134	104	106	146	28	100	204	161	141	115	142	30	257	240
	1	18	133	106	107	150	30	110	230	197	149	109	131	31	258	245
	4	28	139	108	109	162	31	135	242	203	152	120	141	33	276	249
Masai	1	12	123	107	105	143	36	111	194	178	130	119	145	38	218	200
	1	14	142	99	103	142	38	111	192	171	143	129	146	40	232	202
	1	16	146	97	101	141	42	105	202	169	146	127	139	44	243	214
	1	18	154	92	101	140	43	102	202	172	145	121	148	45	240	222
	1	20	154	105	101	143	49	106	208	174	157	119	151	49	241	227
	1	28	154	107	108	151	50	124	202	182	162	123	153	52	260	246

B.H.P. grades, and that in the local sheep the relative lengths of the upper limb bones are similar to those of semi-wild types, and considerably below those for improved breeds. The weight-relationships are not quite the same as the linear relationships. B.H.P. grades show slightly greater relative weights than the Masai for the upper limb bones, possibly owing to their lighter cannon bones, and compare with the values found for semi-wild breeds by Hammond. When compared with the data for improved breeds it is seen that the greatest differences in weight-relationships are found for the later developing bones (humerus, scapula, femur, lumbar and sacral vertebrae).

TABLE 11. *Cannon Weights and Minimum Circumferences as Percentage of Lengths*

			Metacarpal			*Metatarsal*		
Breed	*Age in months*	*No. of animals*	*Length* (mm.)	*Circumference as per cent. of length*	*Weight* (gm.) *per 100 mm.*	*Length* (mm.)	*Circumference as per cent. of length*	*Weight* (gm.) *per 100 mm.*
Grade Black-headed Persians	6	2	113	26·6	13·3	117	22·1	12·8
	8	2	123	27·2	13·8	132	22·0	12·9
	10	1	135	28·2	17·0	144	24·9	16·6
	12	2	131	28·6	19·8	141	25·6	19·1
	14	1	136	28·7	19·8	145	26·3	20·7
	16	2	134	30·0	20·3	141	25·6	21·3
	18	1	133	30·4	22·5	149	27·9	20·8
	28	4	139	30·4	22·3	152	28·6	21·7
Masai	12	1	123	29·0	29·3	130	26·0	29·2
	14	1	142	29·9	26·8	143	27·9	28·0
	16	1	146	29·7	28·8	146	28·3	30·1
	18	1	154	30·2	27·9	145	26·9	31·0
	20	1	154	31·2	31·8	157	25·7	31·2
	28	1	154	32·0	32·4	162	27·2	32·1

In Table 11 the weight per 100 mm. length of cannon bone is compared with the circumference as a percentage of the length. Whereas the hind-cannons have smaller minimum circumferences than the fores, the weight per unit length is not so constantly below that in the fore-cannons. The most striking thing about these figures is the heavier weight per unit length in the Masai cannons. This is due to the larger extremities of Masai cannons as compared with the grade B.H.P. bones. The weight/length ratios of the local sheep compare with the figures for semi-wild breeds and are far below those for improved mutton breeds. Pálsson found that 'a relatively short cannon with a thick shaft but relatively fine and light extremities appears to be associated with early maturity and desirable carcase quality, whilst long bones with a slender shaft but coarse and heavy extremities are indicative of late development and inferior meat quality'. The two local breeds reported upon now, and the local long-tailed sheep previously examined, fall into the last group of poor mutton-quality sheep. In case it might be thought that the introduction of B.H.P. blood caused a reduction in the size of the bone-extremities, reference to the previous paper [3] shows that the local long-tailed sheep have the same low weight, per 100 mm. length, as the B.H.P. grades. The Masai have coarser and longer bones than local

long-tailed sheep, and from this point of view it seems that the latter would form the better basis for mutton-improvement schemes. Any improvement in mutton-qualities will be accompanied by increased thickening of the skeleton, so that if a start is made with animals possessing fine bones with light extremities, the proportion of bone in the improved animals will be kept as low as possible.

Discussion

Masai sheep have longer and heavier bones than either the local long-tailed sheep or the crosses of the latter with Black-headed Persians. The skeletal weights of all Tanganyika sheep are much below those of improved mutton breeds and compare with semi-wild types such as the Soay and Shetland. As is characteristic of unimproved types, the head forms a high proportion of the total skeletal weight in local sheep. Owing to their heavier cannon-bone weights, the proportions of the different skeletal parts relative to the average cannon weights are smaller in Masai than in other local sheep.

The weight-changes in the proportions of the various parts of the skeleton, with age, follow similar lines of development to those reported by Hammond for improved breeds, except that development of the later maturing parts are considerably inhibited in local sheep. The age-changes are also spread over a longer period in the indigenous breeds.

The lengths of the individual bones vary with age in the same manner as found by Hammond, but the time taken to reach mature length is much longer than in improved breeds. All bones in local sheep show considerably smaller thickness-growths than occur in the bones of improved breeds. It has been shown by Hammond that increased thickness in the bones is one of the first effects of mutton improvement. The greatest difference in thickness-development between improved and unimproved breeds occurs in the later maturing bones around which the most valuable joints are situated. It has been found that the introduction of B.H.P. blood into local sheep has not affected the thickness of the bones, and it is therefore unlikely that an improvement in mutton qualities will have been effected. In the same way the weight per unit length of the later maturing bones is very much smaller in local than in improved mutton breeds. In fact, adult local sheep have weight and linear relationships similar to young animals of the improved breeds and obviously stand in great need of improvement if good-quality mutton is to be produced.

Apart from the light weights, the generally short and slender bones and the lack of development of the late maturing bones, local sheep differ in the following respects from improved British breeds: The skull is shallower and narrower (more like the Merino), the lower jaw is slightly more massive, the ribs are narrower and less well sprung, the pelvis is very narrow (again resembling the Merino), the bones of the loin region are small, the scapula, humerus, and femur are shorter and less well developed, but the radius-ulna and tibia-fibula have the same and the cannons a greater length.

The relatively long legs of the local sheep make them appear high off

the ground and shallow in the trunk. This is an advantage, if not an adaptation, to their hard conditions of life, allowing them to move easily over long distances in search of food.

The data obtained are also of value in showing the growth and relative changes in the skeletons of fat-tailed and fat-rumped sheep. Much information has been collected by other workers on age-changes, &c., for improved types of sheep but, as far as I am aware, there is much less information available for unimproved types. It is interesting to observe that whereas the age-changes are of the same kind as recorded for improved types, these unimproved animals never pass beyond the stage of development reached soon after birth in improved mutton sheep. It is well known that poor nutrition retards development, particularly that of the late maturing bones, poorly fed animals thus tending to have skeletal proportions more similar to young than to mature animals. In the present study this factor is not responsible for the unsatisfactory proportions of the adult local sheep, because the animals used in this study were fed according to modern scientific principles. The data recorded may be taken as representing the best development that Tanganyikan sheep can attain, and indicative of the development of hair-coated, fat-tailed sheep in general.

Summary

1. Indigenous Masai sheep show great need of improvement when compared with British mutton breeds.

2. Masai sheep have heavier and longer bones than the local long-tailed sheep but the late maturing characters are not better developed. When judged by the weight/length ratio, the Masai bones are seen to be coarse, particularly at the extremities.

3. The importation of Black-headed Persian rams for crossing with local long-tailed ewes has not improved the capabilities of the progeny for producing mutton, as judged by their skeletal development. It seems unlikely that the mutton quality of local fat-tailed types will be improved either by crossing amongst themselves or with other imported fat-tailed or fat-rumped sheep.

4. Data are given on the skeletal linear and weight changes with age. It was found that though the changes are of the same nature as those in improved breeds, adult Tanganyika sheep never pass beyond the developmental stage attained soon after birth by improved mutton breeds.

REFERENCES

1. M. H. FRENCH, Empire J. Expt. Agric., 1938, **6**, 112.
2. J. HAMMOND, Growth and Development of Mutton Qualities in the Sheep. 1932.
3. M. H. FRENCH, Empire J. Expt. Agric., 1938, **6**, 246.
4. H. PLÁSSON, J. Agric. Sci., 1939, **29**, 544, and 1940, **30**, 1.

(*Received March 3, 1942*)

THE EFFECT OF SEASON ON THE FATTENING OF SWINE AT VARIOUS STAGES OF GROWTH

GEORGE DUNLOP AND ALUN WEST

(*Animal Husbandry Dept., The West of Scotland Agricultural College, Auchincruive, Ayr*)

IN a previous paper [1] it was shown that the adoption of a standard method of controlled individual feeding is essential for the measurement of inherited characters of economic importance in farm animals. The necessity was stressed for exercising control over the temperature and humidity of the immediate environment during long-term experiments in which observations on growth and food-consumption have to be made on succeeding generations of animals. It was suggested that observations on animals fed during the summer months would not be comparable with similar observations made during the winter owing to the effect of seasonal temperature on growth-rate. This paper deals with the effect of seasonal temperature on characters of economic importance in swine under conditions of (1) *ad lib.* group-feeding, and (2) controlled individual feeding, in a piggery where no precautions were taken to equalize the prevailing winter and summer temperatures.

Individual Controlled Feeding

The figures for controlled feeding were obtained from experiments conducted during the period 1932–4 at the Howe Hill Piggery of the Animal Nutrition Research Institute, Cambridge. The piggery is of the Danish type with single brick walls and asbestos-sheet roofing, so that there is usually little difference between the internal and external temperatures. Early in 1932 one side of the piggery was remodelled to accommodate thirty separate compartments for individual feeding. Six lots of experimental animals of similar parentage and under similar conditions of treatment were fed from weaning to bacon weights—three lots during the summer and three during the winter months. All these animals received the same amounts of meals and five lots received the same basal ration. The pigs in the sixth lot were fed on various rations and were killed off shortly after reaching pork weight. In the other lots, however, complete data are available for each animal of its daily food-consumption and weekly live-weight gain from approximately 40 lb. to 200 lb. live-weight.

A number of animals received diets deficient in calcium or factors of the vitamin-B_2 complex; others had received insufficient vitamin A to permit normal growth to bacon weights; the records of all these animals have been deleted. The observations are confined to animals which received nutritively complete diets as evidenced by their growth-rates and the ready consumption of their daily food-allowance. Food refusals were rare in these records and could usually be explained by some factor other than diet. Where they were serious a suitable correction has been made [2].

The ration fed to the 'normal' animals was composed of 30 parts barley meal, 25 parts ground oats, 30 parts white sharps, 15 parts soya-bean meal. To this ration 0·5 to 2 per cent. of ground limestone, 0·5 per cent. common salt, and 0·05 per cent. ferric oxide was added. A few animals made normal progress when the limestone was increased to 4 per cent., and their records have been included in the analyses. The vitamin-A requirement for fattening was met by feeding supplements rich in vitamin A during the suckling period or for a short period after weaning.

The amount of meal fed daily to each animal was in accordance with a scale previously reported [2].

Live-weight gains.—It has been shown that the gain in weight of the pig is proportional to the growth already made [3]. The growth-rates have therefore been analysed at three stages during fattening: (1) at weaning (25–45 lb.), (2) at pork weights (95–115 lb.), and (3) at bacon weights (170–95 lb.). The accurate determination of weekly live-weight gain by single weighings at the beginning and end of each week is difficult owing to the large observational error. Consequently a number of observations was made at the various stages. Until reaching 45 lb. live-weight as many observations as possible (up to 4) of weekly live-weight gains were obtained for each pig. At pork weights the weekly gain was obtained for all animals immediately before they reached 105 lb. live-weight, and again the following week when they had attained 'initial' weights of 106–15 lb. The weekly gains were again observed when the pigs were 170–80 lb., and also during the following week after they had attained weights of 181–95 lb. The average of these figures was taken as the weekly gains of weaners, porkers, and baconers, respectively.

The results are summarized in Table 1. It will be observed that young pigs, whether weaned in May or November, make similar weekly gains. Later, however, the May weaners make the larger gains. At pork weights their weekly increase is 1·4 lb. greater and at bacon weights 2·7 lb. greater than November weaners. This difference is probably wholly accounted for by the temperature of the piggery since the larger gains were made in July and September, compared with January and March, respectively.

Economy of gain.—The records were analysed in the same manner to obtain figures for economy of gain (lb. meal consumed per lb. live-weight increase). The results are shown in Table 2. Again, little difference is apparent between the economy of gain of weaners in November and May. In July, however, porkers require about two-thirds of a pound of meal less for each pound of live-weight gained, compared with porkers in January. Similarly, baconers in September make more economical gains than in March, when they require an extra pound of meal for each pound of live-weight increase. The results also show that the live-weight gains are made for a much smaller meal-consumption at weaning than at heavier weights. The increase in the figure for economy of gain with increasing live-weight can be explained by the greater energy-value of the gain as the pig grows.

TABLE 1. *Weekly Gains of Pigs (lb.) during Growth in Summer and Winter*

Weight-interval (lb.)	*Summer*			*Winter*		
	1932	*1933*	*1934*	*1932–3*	*1932–3*	*1933–4*
25–30	4·0	..	4·0	..	4·5	..
31–5	5·4	4·5	4·8	5·5	5·1	5·3
36–40	5·4	5·0	5·5	4·9	6·3	5·0
41–5	6·0	4·8	6·4	6·0	5·9	5·0
Weaning, average	*5·6*	*4·9*	*5·7*	*5·6*	*5·4*	*5·0*
S.E.	0·19	0·20	0·26	0·41	0·20	0·29
Total No. observ.	24	28	25	18	50	15
95–105	8·7	8·75	8·9	8·5	8·0	7·2
106–15	8·9	9·4	9·6	6·5	7·4	7·5
Pork weight, average	*8·8*	*9·1*	*9·2*	*7·7*	*7·7*	*7·4*
S.E.	0·20	0·27	0·30	0·29	0·19	0·18
Total No. observ.	52	46	24	33	30	50
170–80	11·7	11·8	11·3	8·75	..	9·4
181–95	10·5	11·9	12·3	8·0	..	8·1
Bacon weight, average	*11·3*	*11·8*	*11·8*	*8·6*	..	*8·8*
S.E.	0·46	0·35	0·78	0·78	..	0·31
Total No. observ.	37	28	6	5	..	30

SUMMARY

	Summer			*Winter*		
Weight-interval (lb.)	*Month*	*Total No. observ.*	*Weekly gain (lb.)*	*Month*	*Total No. observ.*	*Weekly gain (lb.)*
Weaning (25–45)	April–May	77	5·4	Oct.–Nov.	83	5·5
Pork (95–115)	July	122	9·0	Jan.	113	7·6
Bacon (170–95)	Sept.	71	11·5	Mar.	35	8·8

TABLE 2. *Economy of Gains of Pigs (lb. of Meal Consumed per lb. Live-weight Increase): Fattening in Summer and in Winter*

Weight-interval (lb.)	*Summer*			*Winter*		
	1932	*1933*	*1934*	*1932–3*	*1932–3*	*1933–4*
25–30	2·8	2·5	2·5	..	2·0	..
31–5	2·2	2·3	2·2	2·4	2·4	2·9
36–40	2·6	3·1	2·3	2·6	2·2	2·7
41–5	2·7	3·4	2·3	2·0	2·6	3·2
Weaning, average	*2·6*	*3·2*	*2·3*	*2·5*	*2·3*	*3·1*
No. of observ.	24	28	25	18	50	15
95–105	3·4	3·5	3·4	3·8	3·7	4·2
106–55	3·5	3·4	3·3	4·6	4·2	4·2
Pork weight, average	*3·5*	*3·4*	*3·3*	*4·1*	*4·0*	*4·2*
No. of observ.	52	46	24	33	30	50
170–80	3·7	3·7	3·8	4·8	..	4·6
181–95	4·0	3·7	3·6	5·0	..	5·5
Bacon weight, average	*3·8*	*3·7*	*3·7*	*4·8*	..	*5·0*
No. of observ.	37	28	6	5	..	30

SUMMARY

Weight-interval (lb.)	*Summer*			*Winter*		
	Month	*Total No. observ.*	*Economy of gain*	*Month*	*Total No. observ.*	*Economy of gain*
Weaning (25–45) .	May	77	2·7	Nov.	83	2·5
Pork (95–115) .	July	122	3·4	Jan.	113	4·1
Bacon (170–95) .	Sept.	71	3·8	Mar.	35	4·9

At smaller weights a greater proportion of flesh, or protein, of high water-content is laid down in each pound of gain, whilst at bacon weight the increase is composed largely of solid fat. On the other hand, if the energy-value of the gain was the same at all stages of growth the larger pig would require less food for each unit of gain owing to its lower proportional basal metabolism.

Length of fattening period.—The records have also been analysed to determine the length of the fattening period in summer and in winter. Forty pounds was taken as the commencing weight, and the time required by each pig to reach a bacon weight of 190 lb. was abstracted from the records. The results are presented in Table 3.

A slight correction is necessary in the figures for the summer of 1933. A number of animals received a ration of high mineral content containing 4 per cent. of calcium carbonate. The ration of all other animals contained ½–2 per cent. The lower net energy-value of the high mineral ration (as the result of the inclusion of an extra 2 per cent. of limestone), or the high calcium-content *per se*, appears to be reflected in the slower rate of gain in the animals.

It will be observed that the animals fed during the summer had the shorter fattening period, amounting on the average to 13 days. This difference is again probably largely accounted for by temperature of the piggery, as are also the small differences between the lots fed during the same seasons of the year.

TABLE 3. *Length of Fattening Period and Food consumed during Fattening in Summer and Winter (between live-weights of 40 lb. and 190 lb.)*

Season	*Summer*		*Winter*	
Year . .	*1932*	*1933*	*1932–3*	*1933–4*
No. of animals .	20	21	20	21
Mean time .	18 wks. 0 days	17 wks. 5 days	19 wks. 2 days	19 wks. 6 days
S.E. . .	±0·64	±0·8	±0·74	±0·98
Average	*17 wks. 5 days** ±0·63		*19 wks. 4 days* ±0·62	
Food consumed lb.	529	525	580	608
S.E. . .	±8·91	±10·35	±4·61	±5·94
Average	*522*† ±6·32		*594* ±5·29	

* Excluding 7 animals on a 4 per cent. $CaCO_3$ diet in 1933. (Mean = 18 wks. 3 days.)
† Excluding 7 animals on a 4 per cent. $CaCO_3$ diet in 1933. (Mean = 551 lb.)

Total food-consumption during fattening.—The total food-consumption of the pigs while increasing in live-weight from 40 lb. to 190 lb. was abstracted from the records. The results (Table 3) show that, up to 190 lb. live-weight, pigs in winter consume 72 lb. meal more than during the summer months. At bacon weights pigs require an extra pound of meal in winter for each pound of gain, and it is evident that if they are fattened to greater weights (say 230 lb.), as at present, they will require in winter an extra cwt. of meal before slaughter.

Group-feeding Data

Experiments were conducted in the same piggery for several years before it was reconstructed for individual feeding. Each year from 1926 till 1932 animals were fattened during summer and winter as in the individual-feeding experiments reported above. In total, there were 31 groups including 261 pigs fattened during the winter months and 23 groups of 202 pigs during the summer periods. The animals were all obtained from the University Farm herd, and winter weaners were frequently full brothers and sisters of the animals which had been fattened during the previous summer.

The pigs were taken over when 10–12 weeks of age, and received the same preliminary ration in the experimental piggery for the next fortnight. Some of the animals were approaching 70 lb. at the first recorded weighing. The age on reaching 70 lb. has been taken as a measure of the growth-rate during the suckling and weaning periods. The different rations used after the experimental groups were made up renders invalid any further comparisons. Each experiment, however, included a fish-meal control group, which invariably reached bacon weight before the other groups in the same trial. The performance of the fish-meal group has been used in comparing the progress of the group-fed pigs in summer and in winter. With 70 lb. as the datum, the live-weight reached 11 weeks later was determined for each animal receiving fish-meal, and the average figure of the group is given in Table 4.

It will be observed that, under group-feeding conditions, autumn litters reach 70 lb. live-weight some 14 days later than spring-farrowed

TABLE 4. *Growth-rates and Fattening under Group-feeding Conditions*

Data from Animal Nutrition Res. Inst. Piggery 1926–31

Season	*Summer*	*Winter*
No. of animals	202	261
No. of groups	23	31
Weaned	April	October
Age when 70 lb. L.W. (days)	$97 \pm 1{\cdot}08$	$111 \pm 1{\cdot}36$
L.W. 11 weeks later (lb.)*	$193 \pm 2{\cdot}62$	$180 \pm 1{\cdot}52$

* Cereal fish-meal groups only.

pigs. It is doubtful, however, if this difference can be attributed to environment since the mean temperature for the period Sept.–Nov. is similar to that for Mar.–May and the individual feeding data showed

that weaners in these two periods have similar growth-rates when fed on the same plane of nutrition. It would appear therefore that the greater growth-rate of spring litters is due to an increased appetite which is satisfied in *ad lib.* feeding but not under conditions of restricted feeding. It was commonly observed in the controlled-feeding experiments that the spring litters consumed their food-allowance immediately they were put on the experiment, whilst the autumn litters required some time to settle down and the food-consumption was erratic during the first weeks. Hammond [3a] has already pointed out the role of increasing periods of daylight on growth and fertility in poultry. The effect is ascribed to stimulation of the anterior pituitary gland, and an increase in the level of its hormones in the blood-stream, which gives rise to an increased metabolism. This theory may also explain the increased appetite and growth-rate of suckling and weaned pigs in the spring months.

During the fattening period the same seasonal difference is evident as under individual controlled feeding. The animals fattened during the summer months make a greater live-weight gain of 13 lb., compared with animals fattened over the same length of feeding period in winter. The data for individual feeding indicate that this is a temperature-effect and that the difference is accentuated somewhat by restricted feeding.

Discussion

From the results reported here it is evident that the time of year during which the observations are made markedly affects the performance of swine. This finding is of interest in the planning of long-term nutrition and genetic experiments, and it is also of importance in conditions of practical husbandry.

In countries where severe winters are experienced, such as Scandinavia and North America, proper attention has been given to heat-conservation in the construction of piggeries [4]. In many piggeries in America where these safeguards have been taken no significant difference has been observed in the rate of fattening in summer and in winter [5].

On the other hand, in Rumania, Kurelec [6] has made observations over a period of 4 years regarding the effects of weather on the fattening of 7,000 Mangalica pigs all fed in the same way. He showed that the results of fattening depended greatly on temperature and were less affected by amount of radiation, duration of sunshine, evaporation of moisture, length of day, or atmospheric humidity. Tables which he drew show the most favourable months for fattening Mangalica pigs.

Piggeries constructed on the Scandinavian plan in Britain have been found cold in use, damp, and of inequable temperature, giving rise to chilly conditions during winter. Deighton [4] has discussed the problem and shown how improvements may be effected to keep the internal environment more constant. Many of these Scandinavian types of piggery in Britain are probably less satisfactory than the older farm piggery in this respect, and in a survey of pig-farming in East Anglia, where there is a mixture of both types, Kitchen [7] found that litters fattened during the warm months of the year reached bacon weight

10–14 days sooner than those fattened during the cold. In a piggery of the Scandinavian type the difference under the same method of feeding, as shown in this paper, is 3 weeks. Over the whole country the loss of efficiency in fattening during winter must be considerable, especially in this type of piggery.

The slower rate of fattening in winter may also be reflected in the official figures for Britain of the monthly supplies of bacon (including salted pork and tinned hams). These show that the number of bacon pigs fed during the winter and available for slaughter in the spring (February to May) is only half of the number fed during the summer months and marketed in the autumn (August to November). It is known that a number of other factors account for this seasonality of production:

(1) Farrowings are more common in the spring than in the autumn.
(2) Higher mortality of autumn litters [8].
(3) Seasonal demand for pork around Christmas, which tempts producers to market their pigs for pork with consequent shortage of bacon in the spring months.

In addition, although the effect may not be so great, the slower fattening-rate of pigs in chilly and damp piggeries during the winter must also play its part on the seasonality of bacon production in this country. Calculation shows that the seasonal difference in fattening rate may account for 10–15 per cent. of the disparity in the seasonal marketing of pigs.

The greater efficiency of fattening during the summer months raises the question whether it is worth while confining the fattening of pigs to this period, particularly when foodstuffs are scarce or high in price. A similar problem exists normally in New Zealand, where an effort is made to carry over, or 'store', autumn-born pigs until the spring flush of cow's milk is available for fattening [9, 10]. Pumpkins, swedes, and carrots are used largely for this purpose. From the data reported here it can be shown that, roughly, one extra cwt. of meal is required for pigs fattened during winter. During periods of scarcity or dearness of foodstuffs, and on farms where the heat-conservation properties of the piggery cannot be easily improved, the New Zealand practice of a store-period for autumn-born pigs may be worth consideration.

Summary and Conclusions

Analyses have been made of the growth-rate, food-consumption, and economy of gain of pigs at different stages of growth fattened (1) in summer, and (2) in winter under conditions of (*a*) individual controlled feeding, and (*b*) *ad lib.* group-feeding.

It is shown that when housed in the modern Scandinavian type of piggery as constructed in Britain, where no control is exercised over the prevailing temperature, pigs take 3 weeks longer to reach bacon weight in winter and consume approximately an extra cwt. of food.

As pigs increase in weight they require more food for each unit of gain. At all stages after weaning more food per unit of gain is required in winter than in summer.

The increased appetite of young pigs during the spring months is

discussed in relation to the theory of increasing periods of daylight giving rise to an increased metabolism via the pituitary.

The need is stressed for control of temperature and environment during long-term nutritional experiments and in genetical studies of factors of economic importance in animals.

The bearing of the results on various aspects of practical pig-feeding in Britain and other countries is discussed.

Acknowledgement:—The group-feeding data were abstracted from experiments conducted by Mr. H. R. Davidson, Mr. A. N. Duckham, and Mr. A. W. Kitchen, to whom our thanks are due.

REFERENCES

1. G. Dunlop and S. Williams, Controlled Feeding Techniques for Measuring Genetical Differences. Proc. 7th Internat. Genetics Cong. 1939, pp. 108–9.
2. G. Dunlop, Methods of Experimentation in Animal Nutrition. J. Agric. Sci. 1933, **23**, 580–614.
3. S. Brody, Growth-rates, their Value and Significance. Univ. of Missouri Agric. Expt. Stat., 1927, Res. Bull. No. 97.

3a. J. Hammond, Fertility in Poultry. Harper Adams Utility Poultry J. 1934, **19**, 1–6.

4. T. Deighton, Ventilation, Temperature and Humidity in Piggeries. Empire J. Expt. Agric., 1940, **8**, 319–23.
5. L. M. Winters, private communication, 1939.
6. V. Kurelec, Effect of Weather on Pig-fattening, Mezogazdas. Kutatas, 1939, **12**, 216–35.
7. A. W. M. Kitchen, Fertility, Mortality, and Growth-rate in Pigs. J. Agric. Sci. 1937, **27**, 611–25.
8. M. Husby, Statistical Data concerning the Pig Stock used for Experiments. 35th Rept. Inst. Animal Nut., Roy. Agric. Coll. Norway, 1933.
9. C. P. McMeekan, Rations for Wintering Pigs. New Zealand J. Agric., 1937, **54**, 36–41.
10. C. E. Ballinger, Winter Feeding of Store Pigs. N. Z. J. Agric., 1940, **60**, 265–69.

(*Received February 9, 1942*)

THE MECHANICS OF MOLE-DRAINING

E. C. CHILDS

(*School of Agriculture, Cambridge*)

MOLE-DRAINING has been practised for about 150 years, but, although the mechanical principles involved are, in the main, elementary, they appear to have been nowhere discussed. Drainage contractors seem well aware, from experience, of the behaviour of their tackle in various degrees of maladjustment and in various conditions of soil, but it nevertheless seems worth while to look into the theoretical basis underlying the action of the mole-plough in order the better to understand observed behaviour, particularly since the gathering momentum of the mole-drainage campaign is necessitating the design and construction of much new equipment.

The elements of the mole-plough are shown in Fig. 1, stripped of all accessory equipment for lifting and manœuvring out of the ground. It

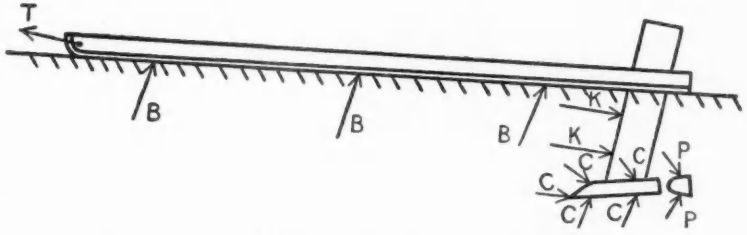


FIG. 1. Diagram showing the elements of the mole-plough with the forces brought into play. T is the haulage tension, B the distributed stress of the ground on the beam, K the stress on the blade, C that on the cartridge, and P that on the bob.

consists of a steel beam hauled by a force T applied at the forward end and carrying a blade and cartridge assembly at the rear end. This beam may rest on the ground in the working position, or may be kept off it, merely forming a rigid connexion from the hitch to the blade. This blade is a strip of steel, usually some 9 in. wide and 0·75 in. thick, and about 3 ft. long, bolted and wedged (or in some other way rigidly fixed) in the beam in a position approximately perpendicular to the latter. It is sharpened at the leading edge, and carries the cartridge at the lower end. The cartridge is a cylindrical billet of steel which may be from 2 to 3½ in. diameter, and is fixed rigidly to the blade by an arrangement somewhat similar to that by which a ploughshare is attached to the plough body, but with the added firmness obtained by the use of one or more rivets. The nose of the cartridge is tapered off from the top to the bottom (the axis of the cylinder being approximately parallel to the land surface, that is to say, horizontal), so that in profile it is seen to be chisel-shaped. The cartridge is usually followed by a freely trailing bob, plug, or expander consisting of a short length of cylindrical steel

bar slightly greater in diameter than the cartridge, tapering symmetrically at the fore end. For the sake of generality, Fig. 1 shows the blade with a certain amount of forward rake, which it has in some designs, and with the cartridge slightly tilted down at the nose, a maladjustment which, whether by design or accident, is far too common.

Nature of the forces on the mole-plough

The tension T needs but little discussion. It is commonly applied by steel cable hauled in by a temporarily stationary steam-engine or its diesel equivalent, or by tractor-winch equipment; in this case the direction of the force is practically parallel to the ground, there being no vertical component. Alternatively, and nowadays with great and increasing frequency, it may be hauled directly by a heavy tractor, and in such circumstances a vertical force component may be introduced, the resultant tension making a finite angle with the ground surface.

The nature of the forces exerted on the various parts of the implement by the soil is determined by the physical properties of the latter. Soil behaves as an elastic body provided the pressure applied to it does not exceed a certain limit; when this limit is exceeded the soil yields and permits the body exerting the pressure to pass through it, itself being permanently displaced in the process. Thus over the whole of the surface of the blade, cartridge, and bob in contact with the soil there is a pressure normal to the surface, and in addition, owing to friction between the steel and soil, there is a shear stress parallel to the line of intersection of the steel surface and a surface parallel to the ground and passing through the point at which the stress is being considered. By symmetry the resultant of the sideways components of these distributed forces is zero, leaving only fore-and-aft and up-and-down components. The distributed forces are indicated by the arrows K (for the blade), C (for the cartridge), and P (for the bob) in Fig. 1; the distribution is not, of course, necessarily uniform. The forces are neither perpendicular to the surfaces at which they act nor parallel to the direction of motion, for they are compounded, as described, of pressure and shear forces. The arrows B indicate the distributed upthrust of the ground surface on the bearing surface of the beam compounded with the shear stress operating for the reasons already stated. When the mole-plough is moving through the soil, the stresses on those surfaces displacing soil are the limiting or yield stresses, whilst those on the surfaces not actually moving through the soil, e.g. the beam-bearing surface, may be less than the limiting value. In addition to the forces already described there are the strictly frictional forces, functions of the velocity of travel, which may be neglected at the speeds at which mole-ploughs commonly move; or at least they do not vary widely in this speed range.

Conditions of equilibrium of the mole-plough

If we imagine a velocity, equal and opposite to that of the mole-plough, to be impressed on the plough-soil system, the problem resolves itself into one of static equilibrium of a rigid body under the external

system of forces already described. In the study of this problem there is scope for experiments both to provide necessary information and to test certain conclusions. Equipment not being available for full-scale experiments, work was consequently done on a model to a scale of 1/24 full size, pulled through plasticine for convenience except for the experiments carried out to provide Fig. 4; these were done in a soil clay. Experiments on this scale cannot, of course, be regarded as more than semi-quantitative, and any conclusions based on them are to be taken as provisional. It is hoped that this paper may point the way to full-scale experiments in the field by those in a position to carry them out, so that recommendations on points of mole-plough design may be made with confidence.

In considering the equilibrium of the mole-plough, we shall choose

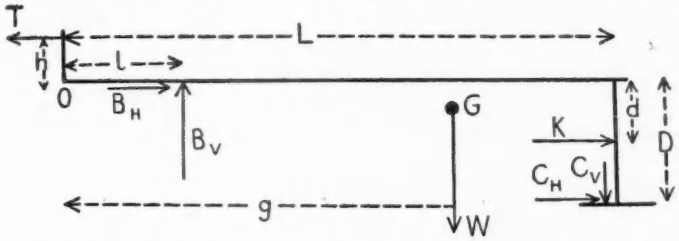


FIG. 2. The force-diagram for the mole-plough. B, K, and C are the resultant forces corresponding to the stresses in Fig. 1, the subscript H referring to horizontal and V to vertical components. W is the weight acting at the centre of gravity G.

the simplest type of 'skid' implement hauled by cable. Any type of implement can be dealt with similarly by slight modifications of the derived equations. Furthermore we shall consider the blade to be set truly perpendicular to the direction of motion (which will be considered horizontal), so that all forces on this element are horizontal. All the distributed forces may be replaced by their resultants acting each at a point, and the resultants may in turn be substituted by their components parallel and perpendicular to the direction of motion. Fig. 2 shows the force-diagram for the mole-plough treated in this way. Since the plough is cable-hauled, the tension T has no vertical component; it is wholly parallel to the direction of motion, as also is the blade force K, owing to the setting of the blade. B_H and B_V respectively are the horizontal and vertical components of the force on the beam, whilst C_H and C_V are the components of the force on the cartridge. The force on the bob is wholly horizontal, both by reason of symmetry and because it is freely trailing; it may therefore be regarded as a contribution to C_H, and since it is not part of the rigid body, no separate force due to the bob is shown in Fig. 2. The mole-plough is to be considered as working steadily at the set depth D, whilst the resultant blade force K acts at a point on the blade at a depth d. The beam-length from hitch to blade is L; the beam resultant upthrust acts at a point l behind the hitch. The haulage-tension can never be applied quite at ground level

(which, we shall see, is the best level), and Fig. 2 shows it applied at a height h above ground.

The conditions for static equilibrium are that the algebraic sums of the horizontal forces, the vertical forces, and the moments about any point shall be separately zero. It is convenient and more illuminating to consider moments of the forces about the nose of the beam, O in Fig. 2, for it is about this point that the plough rotates if, the equilibrium conditions not being satisfied, it lifts from its set depth. The three conditions give us the three equations

$$\left.\begin{array}{ll} (a) & T = B_H+K+C_H \\ (b) & B_V = W+C_V \\ (c) & lB_V+dK+DC_H+hT = gW+LC_V \end{array}\right\}. \qquad (1)$$

In the above equations W is the weight of the mole-plough acting at the centre of gravity G in Fig. 2, a horizontal distance g behind the hitch. In (1c) the moments on the left-hand side (L.H.S.) are the counter-clockwise moments tending to rotate the mole-plough out of the ground, whilst the clockwise moments of the right-hand side (R.H.S.) tend to let it in deeper.

The first thing we notice is that, in (1c), and for a given plough working at a set depth, all the terms are either constant or determined solely by the soil conditions, with the exception of the first term of the L.H.S. With the usual setting of the mole-plough this term lB_V is variable and plays the part of an automatically balancing item, as can also, in certain circumstances, the term hT. To see this, imagine the mole-plough design to be such that, with slightly dipping cartridge, it can just maintain the set depth but is on the point of lifting out; the beam is then not bearing on the ground at any point except at the nose, so that the upthrust B_H must be localized at the nose with l equal to zero; (1c) then loses its first term and the two sides are, by hypothesis, equal. Also by hypothesis C_V is at its maximum, since the cartridge is on the point of lifting, hence any increase of the L.H.S., due to increase of K and C_H and therefore, by (1a), of T, cannot be compensated by an increase of the R.H.S. The counter-clockwise moments then prevail and the mole-plough lifts. If, on the other hand, K, C_H, and T decrease, the clockwise moments tend to prevail, but the cartridge, in trying to go deeper, brings the beam to bear on the ground along its whole length, the resultant upthrust thus being moved back a finite distance l from the nose. The beam bearing surface is, of course, designed to prevent it entering the ground, so that the term lB_V automatically adjusts itself to satisfy (1c). Admittedly C_V might decrease in company with K and C_H, but that such a decrease should be just enough to maintain equality of the two sides of (1c) without alteration of l could only be a fortuitous occurrence. In the limit the upthrust may be brought right back to the tail of the beam. If the L.H.S. is not sufficient even then to satisfy (1c), the mole-plough will rotate on its tail and lift its nose into the air, thus increasing hT until equilibrium is again obtained. Such conditions, so far as the writer is aware, have never yet been recorded.

Magnitudes of the forces and moments involved

Measurements of the forces on the individual parts of the mole-plough are not easily obtained, with the exception of the tension T, and consequently little information is available. Where information obtained from the use of models is employed, the experiments will be found described in appendixes.

The drawbar-pull required to haul a mole-plough in ordinary circumstances of soil, depth, and calibre of channel is about 5,000–6,000 lb. weight; it may be less for shallow small-bore work, and may rise to about 10,000 lb. wt. for, say, a channel of $3\frac{1}{2}$ or 4 in. diameter drawn at a depth of 30 in. in dryish clay. Let us take an average value of 6,000 lb. wt. for a channel 3·5 in. diameter at a depth of 2 ft. Then, neglecting the friction between the beam and the ground in comparison with the great forces opposed to the blade and cartridge, we obtain by substitution in (1*a*)

$$K+C_H = 6{,}000 \text{ lb. wt.} \qquad (2)$$

The neglect of B_H is only justifiable for these rough calculations; it is not intended to give the impression that this force is invariably negligible. Hudson and Hopewell [1], for example, cite evidence which may be interpreted to show that the necessary increase in haulage tension T when B_H is permitted to become large may be sufficient to cause the mole-plough to lift. Information on the ratio between K and C_H is scanty. Experiments with a model (see Appendix I) give $K/C_H = 4{\cdot}0$, whilst in some full-size experiments on a soil which was not a very suitable one, nor in very suitable condition, for mole-draining, Oehler [2] obtained an average value of about 2·0, omitting results from very shallow work. Using this latter value and combining with (2) above, we get

$$K = 4{,}000 \text{ lb. wt.},$$
$$C_H = 2{,}000 \text{ lb. wt.}$$

We shall now calculate C_V from (1*c*), assuming that we have a mole-plough with a 12 ft. beam weighing, say, 350 lb., and a blade, cartridge, and bob assembly of 150 lb. wt., the working depth being 2 ft. We shall further assume that the beam is 'floating', i.e. that it is off the ground except at the forward end, thus obviating the necessity of considering B_V further. This position is the free-working position; we are not considering the case in which the beam is kept off the ground by partial use of the lifting device, a position known to some contractors as running 'on the chain'. We have now to select an appropriate value for d. If the blade force were uniformly distributed, the resultant K would act at the mid-point of the blade, i.e. at a depth of 1 ft. The distribution is almost certainly not uniform, for the deep subsoil is denser and more resistant than the top soil, but on the other hand the top soil may be drier and on that account harder. Since we are making only a rough calculation of magnitudes, it is probably satisfactory if we make a guess at $d = 15$ in.; this value cannot be very far wrong. Finally, let us suppose that our hitch-point is 3 in. from the ground, i.e. $h = 3$ in.; it

cannot easily be made less. Substituting now all the known terms in (1*c*) we get, expressing all lengths as feet:

$$0+(1{\cdot}25)(4{,}000)+(2)(2{,}000)+(0{\cdot}25)(6{,}000) = (6)(350)+(12)(150)+(12)(C_V),$$

from which we get:

$$C_V = 550 \text{ lb. wt.}$$

Direct measurement of the yield value of C_V in full-scale experiments has never been recorded, but experiments with models (see Appendix II)

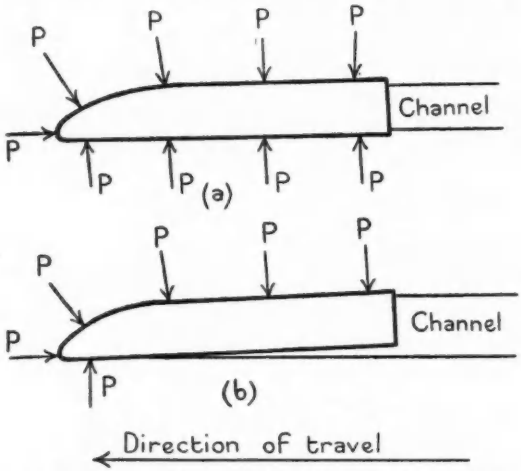


FIG. 3. The stresses on the cartridge (*a*) set parallel to the direction of motion and (*b*) set down by the nose.

and qualitative experience enable us to make an estimate. It appears that this estimate is of the same order as the haulage-tension, i.e. some thousands of pounds weight. We know, for example, that in unfavourable circumstances a steel rope can be broken in the effort to lift the mole-plough out of the ground (the breaking of a similar rope in hauling is not, of course, a rare occurrence). We can also make a rough estimate of the force exerted in winding out the mole by hand, and multiply by the gear-ratio of the winding gear. We are probably safe in estimating the maximum value of C_V at not less than 2,000 lb. wt. It is at once obvious that the free floating of the beam is no evidence that the plough is on the point of lifting, for the value calculated for C_V in the preceding paragraph is little more than a quarter of that which would necessarily be exerted on a lifting cartridge. To elucidate this point we must look in greater detail into the forces on the cartridge.

In Fig. 3 (*a*) we see in profile a cartridge of conventional shape being driven through the soil in such a way that its axis coincides with that of the channel left in its wake, i.e. with its axis parallel to the direction of motion. The closing in of the channel behind the cartridge is somewhat exaggerated; a proportion at least of this closing in must be due

to the elastic properties of the soil. The pressure is indicated by the arrows P perpendicular to the surface; here again the uniformity of indication is not meant to imply uniformity of pressure. In addition there will be the shear components, but since these contribute mainly to C_H and not to C_V we shall ignore them. The pressure over the fore part of the cartridge, where soil is being permanently displaced, must clearly be the maximum which the soil can exert, otherwise it would not yield. Over the after cylindrical part, the cartridge is merely pressing against the already displaced soil, preventing it from expanding back by the small amount shown exaggerated in Fig. 3. If the passage of this part of the cartridge increasingly compacts the soil, diminishing its powers of closing in behind, there will be, and in fact probably is, a steady decrease of pressure P as the tail of the cartridge is approached. Furthermore, by symmetry the resultant force over the cylindrical part of the cartridge is zero in the direction perpendicular to the direction of motion, so that the total force C_V is given by the resultant of the forces acting over the fore or chisel-shaped portion. When, however, the cartridge is tilted down by the nose just sufficiently to raise the sole off the floor of the channel (see Fig. 3 (*b*)), the whole of the upper surface is permanently displacing soil and therefore has the full pressure at the yield-point exerted upon it, whilst the lowest part is clear of the channel and has no pressure at all upon it. In both cases the downward force is given by

$$C_V = \int P\,ds,$$

where ds is an element of the projection of the surface of the cartridge on the horizontal plane and the integral is taken over the whole projection. In case (*a*) it is only the fore part, as we have seen, which makes a contribution to the integral, and only then if P over the upper displacing surface is greater than P over the lower non-displacing surface. In case (*b*), however, the whole of the upper part of the surface contributes to the integral, the contribution of each element being downwards, whilst the contribution of the under part, potentially acting upwards, is zero. Since only a very small tilt is sufficient to change case (*a*) to case (*b*), in effect the cartridge tends to maintain its axis parallel to the direction of motion, for it can automatically vary the force C_V, to suit changing circumstances, within the limits zero to the maximum which the soil can support.

Setting of the mole-plough

We are now in a position to see that there are two chief types of setting, with different principles of maintenance of equilibrium. In the first, if the cartridge has even a slight amount of tilt down at the nose when the beam is resting firmly on the ground, C_V is always at its maximum value and the cartridge is always tending to go deeper, being prevented only by the beam. In this case it is the term lB_V of equation (1*c*) which varies automatically to satisfy the equilibrium conditions. It may be observed that, with this setting, if the mole-plough cannot keep down to its set depth but lifts, excessive dip of the cartridge, so far from solving the problem, only aggravates the trouble. For with very slight

dip the force C_V is at its maximum, and further dip reduces it owing to the reduction of the area of projection of the cartridge on the horizontal plane, this area being proportional to the cosine of the angle of dip. This effect, together with the increased haulage-tension necessitated, increases the balance of the counter-clockwise moments over the clockwise, thereby increasing the tendency to lift. The truth of this conclusion was demonstrated by means of a model.

In the second type of setting the beam exerts no direct control on depth, for it is normally off the ground or freely floating. The term lB_V is therefore always zero, and maintenance of the equilibrium conditions is ensured by the automatic variation of C_V, the cartridge maintaining its set depth with its axis parallel to the direction of motion; it maintains this depth because at no other depth is the axis so alined. In conformity with these views, some New Zealand mole-ploughs are set for depth by tilting the blade-cartridge assembly [1].

We may compare the two types of setting by studying their behaviour when the mole-plough traverses local surface irregularities. It is a feature of a good mole-plough that it ignores such local bumps and hollows, drawing deeper at the bumps and shallower at the hollows so that the depth of the channel below the mean surface-level is constant. To take the floating beam first: when the mole-plough passes through a depression which is of small extent compared with the length of the beam, the nose of the beam reaches the far side before the blade encounters the depression, so that the direction of motion is not affected at the material time. The reduction of depth of working in the depression causes a reduction of the counter-clockwise moment constituting the L.H.S. of (1*c*). The tendency, therefore, is for the prevailing clockwise moments to pull the cartridge in deeper; but a deepening of the work can only take place by a clockwise rotation of the mole-plough about the nose of the beam, and this rotation produces an upward tilt of the cartridge with consequent reduction of C_V. The moments are therefore brought again into equilibrium without the cartridge departing appreciably from its appointed path. When the implement comes to a bump, the momentary upsetting of equilibrium causes a tendency for the cartridge to rise and therefore to dip down by the nose. The consequent increase of C_V again restores equilibrium without disturbance of the mole-channel. It must be realized that this auto-compensatory action is only possible if the beam is sufficiently long, for if it is so short that, by equation (1*c*), the maximum yield force is required to keep the cartridge at its set depth in normal circumstances, no increase in C_V is possible, and a chance bump or local spot of high resistance must cause the mole-plough to lift.

With a firmly bearing beam the action is different. The beam acts as a bridge or cantilever over a local depression by bearing firmly over most of its length on the flat ground outside the hollow. At a bump, however, the plough must quite clearly lift, drawing down again when the bump is passed. Even this is not the worst disadvantage of this setting, as will be shown in the following experiments.

In order to test these views, a model was drawn through a bed of

clay, a hollow followed by a bump being arranged in its path. The model corresponded, to a scale of 1/24th full size, to a mole-plough with 12-ft. beam drawing a 3-in. channel at a depth of about 20 in. The depression was, to the same scale, 4 in. deep and the bump 4 in. high, the length of each being about 4 ft. First the mole-plough was set to pull at the required depth with floating beam, the tail of the beam travelling at the equivalent of about 8 in. above ground-level. The channel, when freshly drawn, was so straight that one could see through the whole length of it. A longitudinal section through the slit and channel was obtained by passing a thread down the mole slit and pulling downwards in the manner of cheese-cutting, and is shown in the upper picture, Fig. 4 (*a*). The slight general curvature is due to warping caused by drying before the photograph was taken, but the slight wave at the beginning of the channel is real and due to the slight change of

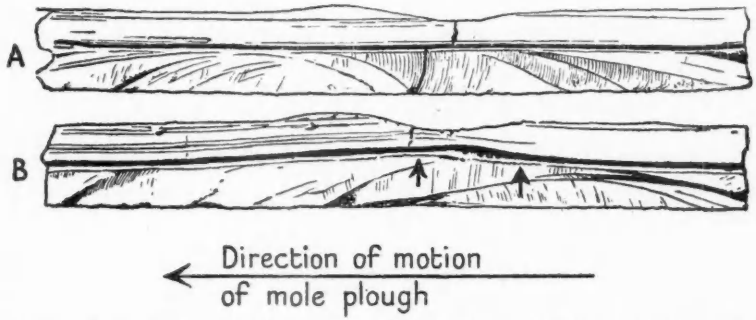


FIG. 4. Channels drawn below an irregular surface by a mole-plough (*a*) with a freely floating beam and (*b*) with beam bearing firmly on the ground. Note the torn and lifted channel between the arrows in (*b*).

direction of motion as the nose of the beam fell into the hollow and then rose on to the bump; it is in any case negligible. It will be seen that the passage of the hollow and bump is without effect on the regularity of the channel. Fig. 4 (*b*) shows a longitudinal section of a mole-channel drawn by the same model at the same depth, but with the setting altered to ensure the firm bearing of the beam on the clay surface. The hollow and bump through which the mole-plough was drawn was made as nearly as possible similar to that of Fig. 4 (*a*). As was to be expected, the bump caused the cartridge to lift, but this lift is not very obvious in the picture because of a very sudden and considerably greater lift, the extent of which is marked by the two arrows in the figure, which occurred when the cartridge was still some distance from the bump. The reason for this is that, as the beam passes over the bump, the nose is kept off the ground, and the upthrust is applied at the point where the beam touches the bump, which becomes the fulcrum about which any rotation of the plough takes place. The effective length of the beam is thus decreased steadily (or alternatively l and therefore lB_V increase steadily) as the mole-plough advances, until a point is reached

at which the moments of the R.H.S. of equation (1*c*) are inadequate to balance those of the L.H.S. The beam then rotates like a seesaw until the nose is down on the ground again, when, the full length of the beam being once more effective, equilibrium is restored and the mole-plough proceeds to the bump and past it, gradually drawing down again to the set depth. The seesaw motion produces an abrupt and substantial lift which is responsible for an irregular torn channel as shown in the photograph. Such a lift is not produced in Fig. 4 (*a*) because, owing to the normal tilt of the beam, the nose passes the bump and is firmly on the ground again before the position of instability can occur. There would therefore appear to be good grounds for designing mole-ploughs so that the beam cannot make contact with the ground at any point except at the nose.

Required strength of the structure

The great variation between mole-ploughs as regards weight of steel and massiveness of construction is a striking feature. It appears to be possible to design quite a light implement to work at a depth as great as 30 in. The question therefore arises whether the more massive types are wasteful of material. It is at once obvious that the breaking of a beam owing to the tensile stress exceeding the ultimate strength of the material is a contingency which may be ignored. With tensile strengths of the order of 25 tons weight per square inch, 5 tons weight per sq. in. would be conventionally a safe stress, so that, with a maximum tension of 10,000 lb. wt., a beam of 1 sq. in. cross-section would be adequate. In point of fact the cable is the weakest link and always breaks first. The strength of the beam and blade is chiefly required to stand up to bending moments. By taking such moments at various points one can easily see that the greatest bending moment occurs at the point where the beam is attached to the blade; the mole-plough is, in fact, structurally similar to a wish-bone with unequal arms, the tension at the nose of the beam and the forces applied by the soil to the blade and cartridge tending to separate the extremities and to break the mole-plough at the angle between the arms.

With a maximum blade force K equal to, say, 6,000 lb. wt. acting at a depth of 1·5 ft. when the cartridge, at a depth of 2·5 ft., is acted upon by a horizontal force of 3,000 lb. wt., the bending moment at the beam-blade junction is 16,500 ft. lb. wt. Both beam and blade must withstand this. It may be found in any text-book on the strength of structures that if M is the maximum moment that a beam, of moment of inertia of cross-section I, will support, then M and I are related by the equation

$$M = IF/D, \tag{3}$$

where F is the maximum tensile stress allowed in the material and D is the distance from the neutral axis to the most strained filament in the beam. If we consider a blade of rectangular cross-section, then D is half the width, since the neutral axis bisects the width. If a is the thickness of the blade, then

$$I = 2aD^3/3 \tag{4}$$

whence, from (3) and (4),

$$M = 2aD^2F/3. \quad (5)$$

Substituting the calculated value of M and a safe stress of 5 tons wt. per sq. in. (expressed as lb. wt. per sq. ft.) we get, for a blade thickness of 1 in. (1/12 ft.),

$$D = 0{\cdot}43 \text{ ft.},$$

so that the full blade width, to withstand the bending moment, must be about 10 in. Very few blades, even in the heaviest tackle, are of these ample proportions, so that the factor of safety can be but small. We can, of course, afford a low factor of safety, for, since the mole-plough never attains appreciable momentum, there is little likelihood of sudden momentary overloads. On the other hand, the blade wears comparatively rapidly, still further reducing the factor of safety. Since the bending moment decreases steadily down the blade, there is perhaps a case for the use of tapering blades. In a similar manner to the above we can calculate that a beam consisting of two channel-section side members bolted together to form an I girder will stand the maximum bending moment if the height of the web is 6 in., the full width across the flanges is 6 in., and the thickness of steel is $\frac{3}{8}$ in., giving a web thickness of $\frac{3}{4}$ in. It may be noted, however, that in designs where the blade is freely pivoted about a bolt through the beam, the setting being maintained by a strut anchored at a forward point on the beam, there is no bending moment transferred to the beam except at points forward of the strut anchorage. At these forward points the moments are much reduced, and consequently such designs can afford to employ lighter beams. There is, in such cases, the added problem of designing the strut to stand the thrust of, say, 6,000 lb. wt. without buckling, using the formula:

$$W = \pi^2 IY/l^2,$$

where W is the load that the strut will support if its length is l, its moment of inertia of cross-section is I, and the Young's modulus of the material is Y. It will be found that quite light struts suffice.

Summary

A study of the mechanics of mole-draining brings out chiefly the point that the cartridge, if properly set, tends to maintain itself at the set depth, ignoring local surface bumps and depressions. The function of producing regular falls in spite of surface irregularities is best left to the cartridge, without making use of the beam as a bridging device, for this latter arrangement can cause serious channel faults. The true value of a long beam is that it enables full use to be made of the self-adjusting powers of the cartridge.

The necessary strength of the mole-plough structure is briefly dealt with.

APPENDIX I

Distribution of Draught between Blade and Cartridge

The model used was equivalent, to a scale of 1/24th full size, to a mole-plough with 18-ft. beam drawing a 3-in. channel at a depth of 2 ft.

The draught with and without the cartridge was measured by applying the tension through a spring-balance. The clay was plasticine. Owing to the low accuracy of the experiment, runs were made in six pairs, the order (with and without cartridge) being randomized in each pair.

Results

Mean draught with cartridge . . .	10·25 lb. wt.
Mean draught without cartridge . . .	8·10 lb. wt.
Therefore mean draught of cartridge . .	2·15 lb. wt.

$$\frac{\text{Draught of blade alone}}{\text{Draught of cartridge alone}} = 3{\cdot}77.$$

Analysis of variance

	Degrees of freedom	*Sums of sqq.*	*Mean sq.*	$\frac{1}{2}\log_e(m.s.)$
Blocks	5	0·979	..	..
Treatments	1	14·083	14·083	1·320
Error	5	0·980	0·196	$\bar{1}$·185
Total	11	16·042	..	..

Whence[1] $z = 2{\cdot}135$.

For $P = 1$ per cent. with $n_1 = 1$ and $n_2 = 5$, $z = 1{\cdot}394$.

Standard error per pull = 0·44 lb. wt., or less than 5 per cent. of mean draught.

APPENDIX II

Estimate of Maximum Vertical Force which Clay can exert on the Cartridge before Yielding

It is not justifiable to calculate the yield-stress over the cross-section of the cartridge from the previous experiment and to obtain the vertical yield-force by multiplying by the area of the projection of the cartridge on a horizontal plane, for much of the clay over the cartridge is weakened by the presence of the slit. A minimum estimate was therefore obtained by measuring the increased draught when the cartridge was changed from the freely floating parallel position to the dipping position without change of depth. The amount of dip being known, the increased area of projection on a vertical plane was calculated and the vertical force was obtained by multiplying up the increase in draught in the proportion (area of projection on horizontal plane)/(increase in area of projection on vertical plane). This ratio was about 8·0.

Results

Mean draught with floating beam . . .	9·6 lb. wt.
Mean draught with dipping cartridge . .	10·3 lb. wt.
Increase in draught due to dipping . .	0·7 lb. wt.

Analysis of variance

	Degrees of freedom	*Sums of sqq.*	*Mean sq.*	$\frac{1}{2}\log_e(m.s.)$
Blocks	5	44·5402	..	..
Treatments	1	1·6875	1·6875	0·262
Error	5	0·5900	0·1180	$\bar{2}$·932
Total	11	46·8177	..	..

[1] See R. A. Fisher's '*z*' table, *Principles and Practice of Field Experimentation*, by J. Wishart and H. G. Sanders.

Whence $z = 1{\cdot}330$.

For $P = 1$ per cent., with $n_1 = 1$ and $n_2 = 5$, $z = 1{\cdot}3943$, or, for $P = 5$ per cent., $z = 0{\cdot}9441$.

The significance is little short of the 1 per cent. point.

Standard error per pull = 0·34 lb. wt., again less than 5 per cent. of the mean draught.

Increase in draught 0·7 lb. wt.

Therefore maximum vertical cartridge force = 5·6 lb. wt., or just over half the mean draught of the mole-plough. If this ratio is maintained at full scale, then the maximum vertical cartridge force for a tension of 6,000 lb. wt. is about 3,000 lb. wt.

A measurement of the direct upward pull necessary to lift the model out of the clay gave a value of 8·0 lb. wt., rather greater than the result of the above experiment.

A value for C_V max. may also be obtained from Fig. 4 (*b*). The point at which the mole-plough began to lift was about 3 in. from the bump, i.e. a beam length of 3 in. was just on the point of instability. Unfortunately, it was not realized in time what was happening, and no tension measurements were taken, but assuming a pull of 10 lb. wt., distributed between blade and cartridge in the ratio 7: 3, and with the working depth of 1·0 in., we can take moments about the fulcrum, in order to find C_V; we get:

$$(0{\cdot}5)(7)+(1{\cdot}0)(3)+(0{\cdot}35)(10) = (3{\cdot}0)(C_V),$$

where the height of the hitch-point in the cocked-up nose above fulcrum level is 0·35 in., and, on this scale, the weight of the model may be neglected. Hence

$$C_V = 3{\cdot}3 \text{ lb. wt.},$$

or one-third of the haulage tension, i.e. 2,000 lb. wt. at full scale. This last experiment was, of course, not carried out in the same material as the others, but in rather wet soil clay. It appears to provide a convenient means of determining C_V at full scale.

Acknowledgement.—I wish to place on record my debt to Mr. R. G. Kendall for many lively discussions, in the course of which I have been able to tap the fount of accumulated experience of a progressive contractor.

REFERENCES

1. A. W. Hudson and H. G. Hopewell, Mole-draining in New Zealand. Massey Agricultural College, 1940, Bull. No. 2.
2. T. Oehler, Ein neues Verfahren zur Herstellung von Maulwurfdräns. Der Kulturtechniker, 1933, **36**, 200–10.

(*Received April 10, 1942*)

CACAO BY-PRODUCTS IN PIG FEEDING: COCOA-CAKE MEAL AND DE-THEOBROMINIZED COCOA-CAKE MEAL AS FEEDING-STUFFS FOR PIGS

R. BRAUDE AND A. S. FOOT

(*National Institute for Research in Dairying, University of Reading*)

Introduction.—Numerous investigations have been made on the value of different cacao[1] by-products as feeding-stuffs for farm animals. The general conclusions which may be drawn from past work with pigs are discouraging but not definite. Some confusion exists in the literature as to the particular type of cacao by-product used in many of the experiments, but it appears that most of the difficulties encountered were associated with the presence of theobromine or other toxic factor in the by-product.

The object of the experiments reported here was to investigate the value of fat-extracted cocoa-cake meal as a substitute for a part of the cereal meal in the normal diet of pigs, and to find out if the feeding-value could be increased by commercial extraction of most of the theobromine.

In the manufacture of chocolate, cacao beans are first pressed in expeller presses to reduce their fat-content to about 10 per cent. The residue, 'expeller cake', is further extracted with fat solvents, and is then dried and ground to give the cocoa-cake meal. The detailed composition of the cocoa-cake meal which we used is given in Table 1. Its theobromine-content is high, varying between 2·5 to 2·7 per cent.

TABLE 1. *Chemical Composition of Feeding-stuffs and Experimental Mixtures used*

	Moisture	*Crude protein*	*Ether extract*	*Carbo-hydrates*	*Fibre*	*Ash*
Weatings . . .	14·4	13·8	4·4	57·5	6·0	3·9
Cocoa-cake meal* .	11·4	23·1	1·1	51·1	6·4	6·9
De-theobrominized cocoa-cake meal† .	13·0	23·2	2·8	46·3	7·7	7·0
Barley meal . .	12·2	12·1	2·4	64·8	5·7	2·8
Ground oats . .	13·2	7·9	6·3	59·4	10·0	3·2
Crushed wheat . .	18·0	9·2	1·8	66·1	3·3	1·6
Meat meal . . .	10·8	59·2	13·5	1·0	..	15·5
Lucerne meal . .	8·5	16·4	2·3	43·0	21·6	8·2
Mixture A . . .	13·48	16·84	4·78	52·42	5·83	4·65
Mixture B . . .	13·24	17·58	4·53	51·90	5·86	4·89
Mixture C . . .	13·37	17·59	4·66	51·51	5·98	4·89
Mixture D . . .	13·26	18·34	4·53	50·63	6·10	5·14

The minerals not included.

* Contains 2·5 to 2·7 per cent. theobromine.

† Contains 0.45 per cent. theobromine (after extraction).

[1] The correct spelling for the tree and its seed is *cacao*, that for the finished products is *cocoa*.

The cocoa-cake meal used was supplied by Messrs. Cadbury Brothers Limited, Bournville, who also removed by extraction with a suitable solvent the greater part of the theobromine, reducing the content to 0·45 per cent.

Experiment I

Experimental method.—Twenty-four home-bred Large White weaners selected from 4 litters were divided into 4 groups each containing 6 pigs. The groups were housed in 4 large pens in a piggery of the Danish type, the animals in any one group being, as far as possible, selected for similarity to each other in initial weight, sex, and litter. Group 1, the control group, received a normal fattening mixture A, which has been shown on other occasions to be successful. Group 2 received mixture B, similar to mixture A apart from the replacement of 8 per cent. of the weatings by cocoa-cake meal. Group 3 received mixture C, identical with mixture B except that the cocoa meal had previously been extracted to remove the theobromine. Group 4 received mixture D in which 16 per cent. of the weatings had been replaced by an equal amount of cocoa-cake meal from which the theobromine had been extracted. The composition of each mixture is given in Table 2.

TABLE 2. *Composition of Meal Mixtures*

	Group 1 (Control) Mixture A	*Group 2 Mixture B*	*Group 3 Mixture C*	*Group 4 Mixture D*
Weatings	50	42	42	34
Cocoa-cake meal*	..	8	..	..
De-theobromized cocoa-cake meal†	..	..	8	16
Barley meal	15	15	15	15
Ground oats	10	10	10	10
Crushed wheat	10	10	10	10
Meat meal	10	10	10	10
Lucerne meal	3	3	3	3
Limestone	1½	1½	1½	1½
Salt	½	½	½	½

* Contains 2·5 to 2·7 per cent. theobromine.
† Contains 0·45 per cent. theobromine (after extraction).

All the mixtures were made by hand in the piggery, and their constituents were chemically analysed by the Institute's Chemistry Department. The results of these analyses are given in Table 1, together with a calculated chemical composition for each of the meal mixtures used in the experiment.

The pigs in each group were fed collectively, receiving the meal in the form of a wet mash, 3 lb. of water being allowed for each pound of meal. No extra water was supplied.

The experiment began on October 10, 1940. At the start the average weight of all the pigs was 63·08 lb., and all were kept on their particular diets till they reached bacon weight. The average final weight was

194·96 lb. The data reported cover an experimental period of 126 days, after which all the pigs, irrespective of weight, were slaughtered.

During the experiment the pigs were weighed once weekly, and the amount of meal fed daily was based on their live-weight according to a definite scale. The meals were weighed out and fed twice daily. The diets were introduced gradually during the first week of the experiment. The health, appetite, and general condition of the pigs were carefully observed.

Results

Growth.—Table 3 gives details of the growth of the experimental animals and Fig. 1 shows the average growth-curves for the pigs on each treatment. From Fig. 2, which shows the average daily live-weight

TABLE 3. *Weight in Pounds of Experimental Pigs (Expt. I)*

	Initial group weight	*Initial av. wt. per pig*	*Final group weight*	*Final av. wt. per pig*	*Total group gain*	*Average gain per pig*	*Average daily gain per pig*
A. Control (no cocoa-cake meal)	381	63·50	1220	203·33	839·0	139·83	1·109
B. Untreated cocoa-cake meal 8 per cent. . . .	310*	62·00	936	187·20	626·0	125·20	0·993
C. Cocoa-cake meal 8 per cent. treated	381	63·50	1189	198·16	808·0	134·66	1·068
D. Cocoa-cake meal 16 per cent. treated . . .	388	64·66	1147	191·16	759·0	126·50	1·003

* Five pigs only taken into consideration owing to the death of the sixth pig after 6 weeks of the experimental period.

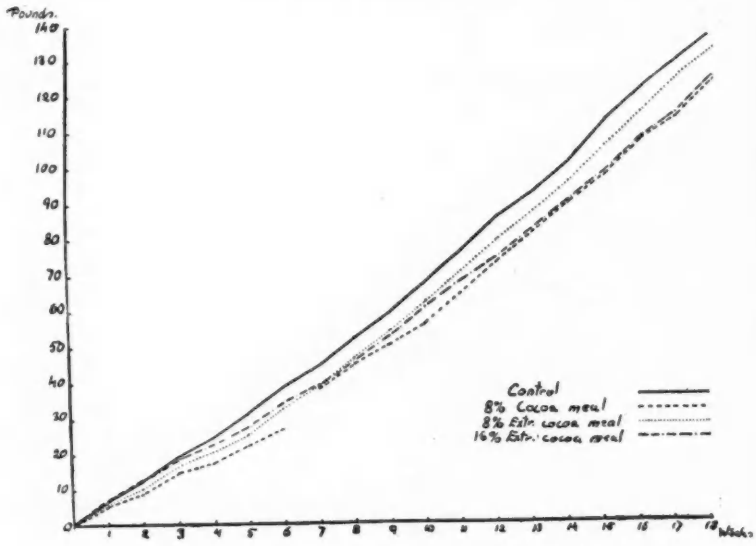


Fig. 1. Average growth-curves of experimental pigs.

gains based on fortnightly weighings, it is evident that all the animals were affected, some more, some less severely, by the change to the experimental diets; and it took 4–5 weeks to get over the growth-retarding effect caused by the change.

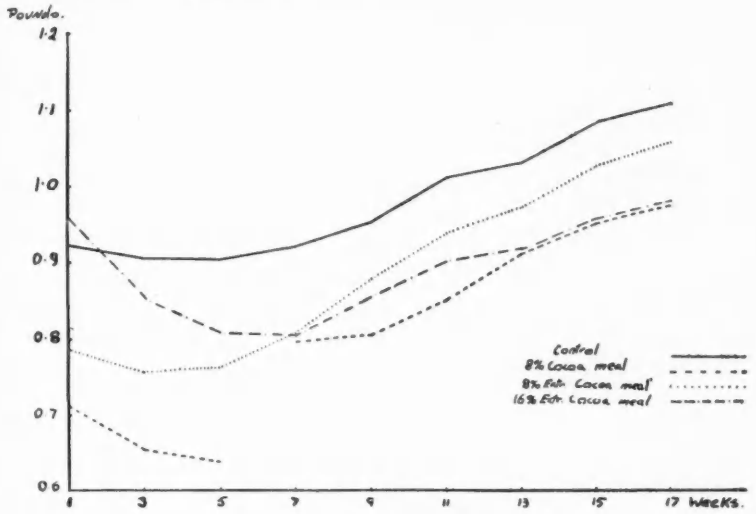


Fig. 2. Average daily live-weight gains.

Throughout the experiment the control group showed a better average growth-rate than the other groups. Although the differences were not statistically significant, the slowest rate of growth was shown by the animals in group 2, receiving 8 per cent. of untreated cocoa-cake meal. One of the pigs in this group died during the sixth week of the experimental period, and this group appeared the poorest lot throughout.

The pigs in group 3, receiving 8 per cent. of theobromine-free cocoa-cake meal, gained in weight more slowly than the pigs in the control group, but their growth-rate was still quite satisfactory and better than that of group 2. Pigs in group 4, receiving 16 per cent. de-theobrominized cocoa-cake meal, took the longest time to accustom themselves to the experimental diet, and their growth-rate was slower than that of the control group or of group 3.

Health and appearance.—In accordance with expectation all the pigs in the control group remained in excellent health throughout the experiment. On the other hand, the health of the pigs in group 2 was evidently affected by the introduction of the untreated cocoa-cake meal, for after a few days the pigs lost their appetite, appeared lethargic, and their coats became dirty. Three of the pigs were more severely affected than the others. One died after 6 weeks on the experimental diet. The two others severely affected eventually recovered, and 8 weeks after the beginning of the experiment all the five remaining pigs in this group began

to improve rapidly in condition. Their appetite became normal, and towards the end their appearance was almost normal, except that their coats remained rougher and dirtier than those of the pigs in any of the other groups.

The pigs in groups 3 and 4 appeared during the first few weeks a little lethargic and for a few days their appetite was slightly subnormal, but they recovered very quickly. After a few weeks a difference in appearance between the pigs in groups 3 and 4 and the pigs of the control group was still noticeable; their coats were rougher and dirtier. The pigs were inclined to keep dirty partly because the crushed wheat in the ration was not totally digested, some grains of wheat appearing in the dung and causing the pigs to search for them in the dung passage.

The veterinary examination of the dead pig from group 2 showed extensive pneumonia affecting the entire right lung and a part of the left one. The lungs were firmly attached to the thorax. Creamy yellow pus was observed. The heart was floating in a considerable quantity of pericardial fluid contained in a thickened pericardial sac. The small intestines showed patchy inflammation. The liver was much enlarged, weighing 3·4 lb. The average liver-weight for a pig of 50 lb. live-weight is about 1½ lb. Some of the livers of the five baconers from group 2 were also found to be somewhat enlarged, but no enlargement was observed in any of the other pigs.

Food-consumption.—Details are given in Table 4 of the amount of food consumed by each group, the average amount consumed per pig, and the food-consumption for 1 lb. live-weight gain. There were no marked differences in food-consumption between the experimental groups; the utilization of food in groups 1 and 3 was nearly identical and somewhat better than that in groups 2 and 4.

TABLE 4. *Food-consumption (pounds)*

	Group 1 Mixture A	*Group 2 Mixture B*	*Group 3 Mixture C*	*Group 4 Mixture D*
Fattening meal (total) .	3594·9	2799·6*	3502·7	3486·9
Fattening meal (per pig).	599·15	559·80	538·78	581·15
Meal, per 1 lb. live-weight gain	4·28	4·47	4·33	4·59

* Five pigs only taken into consideration.

Experiment II

In view of the results of Expt. I, a simple test was undertaken to find out whether untreated cocoa-cake meal could be fed to older fattening pigs without causing digestive disturbance or interfering with growth. By introducing the cocoa meal at a later stage in the fattening period we expected to avoid much of the detrimental effect of the material shown in Expt. I.

Twelve Large White weaners were kept together in a paddock and fed on normal fattening mixture until they reached average live-weight of 123·16 lb. They were then divided by lot into two groups. A control group (6 pigs) remained on the normal fattening diet (mixture E), whilst

an experimental group (6 pigs) was put on a mixture F, which was similar to mixture E apart from the replacement of 10 per cent. cereals by untreated cocoa-cake meal. The composition of the two mixtures was as follows:

	E	*F*		*E*	*F*
Weatings	50	44	Cocoa-cake meal		10
Barley meal	20	20	Lucerne meal	2	2
Ground oats	14	10	Dried yeast	2	2
Meat meal	10	10	Limestone	1½	1½
			Salt	½	½

The animals were fed according to the same scale as in Expt. I, but the food was measured out by volume instead of by weight. This resulted in a less accurate control of food-intake. The pigs received the experimental diets during 50 days.

Table 5 gives the live-weight gains of all the pigs throughout the test period, as well as average daily live-weight gains, dead-weights, weights of liver, and these expressed as percentage of dead-weight.

TABLE 5. *Weight in Pounds of Pigs in Experiment II, including Liver Weights*

	Pig no.	*Initial live-weight*	*Final live-weight*	*Total live-weight gain*	*Daily gain*	*Dead-weight*	*Weight of liver*	*Weight of liver as % of average dead-weight*
Experimental group	2683	136·0	194·0	58	1·16	134·0	3·25	4·35
	2684	122·0	206·0	84	1·68	135·0	4·00	5·40
	2686	114·0	177·0	63	1·26	123·0	3·1	3·81
	2688	125·0	189·0	64	1·28	136·0	4·0	5·44
	2693	144·0	228·0	84	1·68	168·0	4·5	7·56
	2703	143·0	214·0	71	1·42	152·0	4·2	6·38
Average for the group		130·66	201·33	70·66	1·41	141·33	3·84	5·49
Control group	2687	114·0	192·0	78	1·56	133·0	3·8	5·05
	2689	122·0	196·0	74	1·48	142·0	4·25	6·03
	2691	136·0	216·0	80	1·60	155·0	4·3	6·66
	2699	108·0	186·0	78	1·56	139·0	4·0	5·56
	2700	93·0	181·0	88	1·76	125·0	4·15	5·19
	2701	121·0	203·0	82	1·64	146·0	4·3	6·27
Average for the group		115·66	195·66	80·0	1·60	140·00	4·13	5·79

The data show that the inclusion of 10 per cent. cocoa-cake meal into the diet of the pigs caused only a slight decline in the growth-rate.

No abnormal symptoms were noticeable in either group. The only apparent difference between the two lots was in the coats: those of the control pigs were smoother and cleaner, giving these animals more 'bloom' than the pigs receiving the cocoa-cake meal. The dung of the latter pigs was always of a typical chocolate colour, but the faeces were well formed, and there was no evidence of digestive disturbance or toxic effect.

The results of this test, in which the pigs were already partly fattened when first given the cocoa-cake meal, do not support the suggestion that the material causes enlargement of the liver.

Discussion

Group-feeding is not the most satisfactory technique for demonstrating with precision the relative qualities of different diets. Variation within the groups caused by competition at the trough is the most serious disturbing factor. Unless several replicas are undertaken, the results of group-feeding trials with only a limited number of animals in each group must be interpreted with caution. The solution provided by these experiments to the problems mentioned at the beginning of this report cannot therefore be regarded as other than tentative. Nevertheless, the following conclusions may reasonably be drawn.

Untreated cocoa-cake meal when given to 10–12 weeks' old pigs at the 8 per cent. level causes some dietetic disturbance which may be fatal; as the pigs grow older they are able to overcome its ill effects upon their digestive system. The compound in the cocoa-cake meal causing the trouble appears to be the theobromine, as no similar symptoms were encountered in pigs which received the theobromine-extracted cocoa-cake meal. The overcoming of the toxic effect may have been due to the fact that with the increase in age and weight of the pigs the amount of cocoa-cake meal eaten in proportion to the live-weight declines, and possibly the older animals are able to deal with the smaller percentage of theobromine extracted per unit body weight.

The second experiment appears to justify this conclusion: it shows that untreated cocoa-cake meal can be fed to older pigs, say about 20 weeks' old, or after they have reached 120 lb. live-weight, without causing any ill effect.

As regards the food value of the de-theobrominized cocoa-cake meal for fattening pigs, it appears that a replacement of wheat offals to the extent of 8 per cent. of the ration can be successfully undertaken throughout the fattening period provided the meal is introduced gradually. The extent of replacement may be increased to 16 per cent., but under these circumstances a slower rate of growth must be expected.

Summary

A group-feeding experiment with 24 pigs showed that when cocoa-cake meal is fed at an 8 per cent. level it may cause digestive disturbances and even death. A second experiment with 12 pigs showed that untreated cocoa-cake meal can be fed successfully to pigs at 10 per cent. level provided it is not introduced into their diet before they reach about 120 lb. live-weight. After extraction of the theobromine the meal is rendered harmless also to younger pigs, and can be fed with satisfactory results to fattening pigs at the rate of 8 per cent. In special circumstances the rate may be increased up to 16 per cent., but the rate of growth of the pigs will then be retarded.

Acknowledgements.—The authors express their thanks to Dr. S. J. Rowland, who made all the chemical analyses involved, and to Messrs. Cadbury Brothers, Ltd., Bournville, who kindly supplied the cocoa products.

(*Received February 9, 1942*)

RINDERPEST IN TANGANYIKA TERRITORY

H. J. LOWE

(*Director of Veterinary Services*)

WITH PLATE 6

Introduction.—Rinderpest or Cattle Plague is a highly infectious and contagious disease of bovines and of some species of game animals caused by a filtrable virus, and in areas where the cattle have a high degree of susceptibility the resulting mortality may reach as much as 100 per cent. Although in these times we have means such as vaccination at our disposal for preventing such catastrophic consequences, nevertheless it will be appreciated that the problem of controlling the spread of the disease is of the utmost importance, particularly to those countries where the value of the live-stock industry is high, e.g. the Union of South Africa. Our knowledge regarding the relationship between game animals and rinderpest is far from complete and is a subject that is now engaging our attention; it may be said here that certain species are known to be highly susceptible, such as buffalo, eland, greater kudu, giraffe, and wild pig. Other species such as wildebeeste (gnu) are also known to be susceptible to the disease, but to a lesser degree. These factors complicate the problem of control of the infection in eastern and central Africa where game abound, and particularly over large stretches of country where native inhabitants are rare or even non-existent, and therefore where information regarding the existence of the disease is lacking. Rinderpest does not affect elephants, equidae, or carnivora.

History.—The early history of rinderpest in Africa is to a large extent conjectural, but it is generally believed that it is a comparative newcomer and found its way from Asia into Egypt and thence southwards up the Nile to eastern Africa, where it is thought to have arrived about 1890. The disease spread fast and wide through Kenya, Uganda, and Tanganyika. The rapidity of advance was determined to a very great extent by the density of the susceptible animal population, both cattle and game, so that, just like a bush-fire, the conflagration died down for a while owing to a paucity of inflammable material only to flare-up again when conditions became more favourable.

At any rate, all trace of the epizootic in its southward advance appears to have been lost in the sparsely inhabited regions lying between southern Tanganyika and the Zambesi river until it reappeared in Southern Rhodesia in 1895, whence it spread rapidly into the Transvaal and swept southwards to the Cape.

The history of what is now the Union of South Africa during the years 1896–7 is largely the lamentable story of the ruin and devastation caused by rinderpest, together with the vigorous efforts of Koch, Kolle, Turner, Theiler, and others to combat it. By 1902 the infection had been finally eradicated in South Africa, but not before it had taken its terrible toll of cattle and decimated the game. Since that time rinderpest has not been present on the continent of Africa south of Tanganyika

Territory. In fact Tanganyika has been described as 'the keeper of the gate' in this connexion. It is therefore little wonder that the veterinary authorities in the Union, Southern and Northern Rhodesia, High Commission Territories, Nyasaland, Portuguese East Africa, and Portuguese Angola, have always displayed anxiety lest their countries should again be subjected to such a visitation.

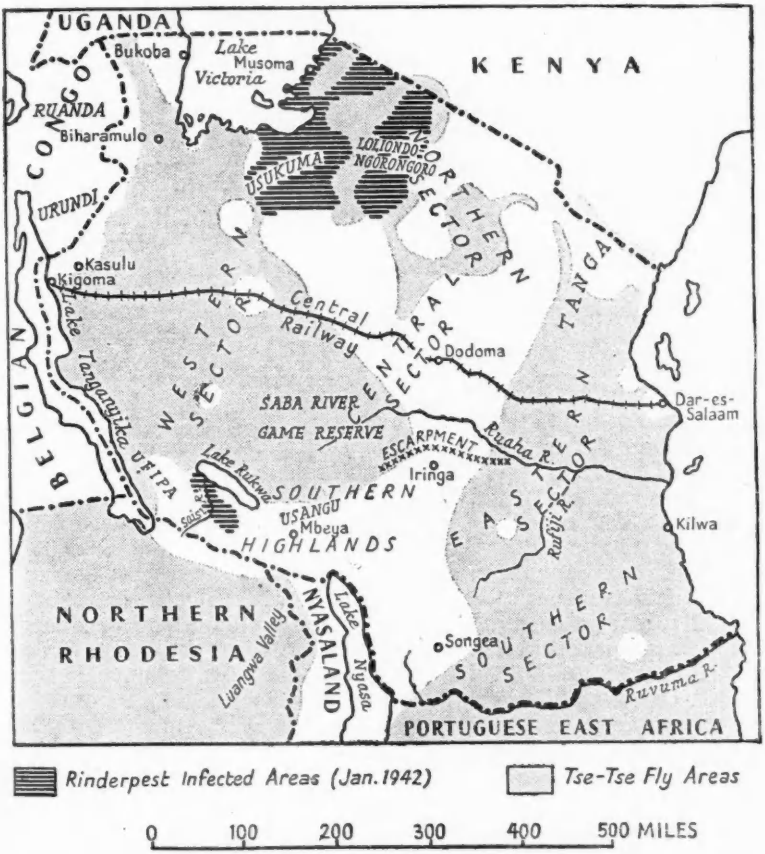
It is noteworthy that during the last war when Tanganyika (then known as German East Africa) was the main battle-field of the East African campaign there was a distinct danger of cattle plague being carried southwards; the Union and other southern territories provided a Rinderpest Commission, under the leadership of the late Mr. C. Gray, Chief Veterinary Officer of the Union, which was charged with the duty of creating an immune belt of cattle between the southern end of Lake Tanganyika and the northern end of Lake Nyasa. Heavy mortality followed the operations of the Commission, not necessarily from rinderpest, but associated in the native mind with the inoculations; and this is mentioned here because it had a bearing on the attitude of the local stock-owners to the vaccination campaign of 1940.

The formation of a civil veterinary department in Tanganyika Territory towards the close of 1918 relieved the southern states of the task of preventing the extension of rinderpest, and these responsibilities were shouldered by this department under Lt.-Col. F. J. McCall. The first objective was the eradication of rinderpest in that part of the Territory lying south of the Central Railway, and after hard fighting and many disappointments and reverses success was eventually achieved in 1927. The operations were continued northwards, and six years later there were only two small areas situated near the Kenya border where rinderpest was active. Alas, it was a short-lived victory. The notorious trade depression of 1930–5 had set in and reduction in funds and retrenchment of staff were the order of the day. A new rinderpest policy was ordained which, whilst allowing the disease to go uncontrolled in the north, bade us interpose a belt of immunity between it and the south where outbreaks were to be circumscribed and suppressed as quickly as possible. This policy broke down for various reasons, and gradually rinderpest spread southwards again until in 1938 it had reached the foothills of the Iringa escarpment about 100 miles south of the Central Railway.

This experience proved one point: that it is almost impossible to maintain a rinderpest-free area in east Africa where it is contiguous with an area where the disease is allowed to remain uncontrolled. There is no topographical or physical feature in this country which forms any kind of natural barrier to the spread of the disease. The fight against rinderpest must be continued to the point of complete eradication. This failure to stem the tide had attracted the anxious attention of the Union of South Africa and other southern states, and a series of Rinderpest Conferences was begun and attended by the Directors of Veterinary Services of the Union of South Africa, Southern and Northern Rhodesia, Nyasaland, Kenya, and sometimes by representatives of the Belgian Congo and Portuguese East Africa.

My main purpose in this article is to describe the measures which have

been taken in recent years to combat rinderpest and to discuss the results which have appeared so far, but in order to enable my readers to obtain a true appreciation of the present position it is essential that they should have the foregoing historical background.



Another question which may require some elucidation is why the disease has not spread southwards through that part of Africa lying west of Lake Tanganyika, i.e. Belgian Congo. The answer is, I think, that there are very few cattle in the Congo on account of tsetse-fly, and I believe very little susceptible game on account of the generally low-lying swampy nature of the terrain. What few cattle and susceptible species of game do exist are separated by great distances and by formidable permanent rivers, which together with extensive swamps form a reasonably secure barrier to the passage of infection.

The Country.—Tanganyika Territory comprises an area of about

365,000 sq. miles (more than 1½ times the size of France), with a population of approximately 6 million people and containing some 5½ million cattle and about an equal number of sheep and goats (combined).

Rinderpest-control measures in this Territory have always been based on the principle of suppression from the most southerly focus northwards, in order to afford the maximum protection to the countries to the south; so from 1938 onwards the scene of operations against rinderpest was almost entirely confined to that part lying south of the Central Railway which runs from Dar-es-Salaam to Kigoma on Lake Tanganyika. A glance at the map will show that this line divides the country roughly into halves. This railway is mentioned frequently in official and other reports, not because it has any significance as a barrier to the spread of rinderpest—it presents no obstacle whatever in this respect—but because it gives a convenient line of demarcation. Most of the larger cattle areas of the Territory lie north of this railway.

In order to follow intelligently the course of events to be described it will be necessary to study the country over which the operations took place and also the nature of the operations themselves.

The area can be divided into three parts:

(*a*) The Eastern Sector, comprising a belt 200–300 miles wide (east to west); is low-lying, heavily wooded, and almost entirely devoid of cattle owing to the presence of tsetse-fly, but in it game abound. During the rainy season (January to June) communications except on foot are difficult and sometimes quite impossible.

(*b*) The Western Sector, with its western boundary on the shore of Lake Tanganyika and extending eastwards for about 300 miles, is also tsetse-infested and therefore holds few cattle but much game.

(*c*) Between the above-mentioned two sectors is sandwiched the cattle-belt which runs southwards through a bottle-neck on the Ruaha river 90 miles south of Dodoma, over the Iringa escarpment, whence it spreads fanwise in a south-westerly direction to Songea, Mbeya, and Ufipa. It includes all the southern highlands of the Territory, which in parts reach an altitude of 10,000 ft. and contain nearly one million head of cattle.

The Operations.—In dealing with rinderpest in Tanganyika we divide the operations into two main divisions: the Intelligence Service and the Inoculating Service. The former is again split up into the intelligence service in game areas and in cattle country. The distinctions are not always closely drawn, because in some cases cattle and game intermix, but in broad outline the game areas are in the tsetse belts where no domestic stock exists. It will be appreciated that the officer in executive charge of a rinderpest campaign must have full and reliable information concerning the presence of the disease in cattle and game in the area over which he is working, and for this purpose a fairly large staff of European Assistant Livestock Officers, Stock Inspectors, and Game Observers, supported by ample numbers of trained African personnel is required.

The Inoculating Service consists of units, each in charge of a Veterinary Officer with European Stock Inspectors and qualified African Veterinary Assistants and Veterinary Guards. Their work includes the

necessary propaganda to the native stock-owners through the officers of the Provincial Administration, the construction of crushes at selected points, and the arrangement of a time-table to ensure the minimum delay in completing the inoculations. The Veterinary Officer in charge of each unit must see to it that his equipment (including syringes, &c.) is in working order, and that supplies of vaccine and virus are demanded as required. The officer in executive charge of the group is responsible for informing the laboratory service well in advance as to his requirements of vaccine, virus, and other laboratory products, and for seeing that each unit is kept supplied. This is not always as easy as it looks, especially when head porterage has to be employed. If the personnel is working in areas where food is unobtainable locally, arrangements have to be made for feeding them.

Treatment of Animals for Rinderpest

Anti-rinderpest serum.—At this point the methods of control used by the Inoculating Units should be explained. Up to 1932 we in Tanganyika Territory relied to a large extent on a system of quarantine of infected herds and the protection of in-contacts by an injection of anti-rinderpest serum. This method had two main disadvantages: the quarantine could not always be effectively maintained over the long periods necessary; and not only was the production of serum expensive but the protection which it set up in the animal body disappeared in 10–14 days. In consequence further injections had to be given, and this again increased the cost and involved more work for the staff. On the other hand, it was a 'safe' method in that it caused no mortality. The only alternative known to us at that time was the 'double-inoculation' or 'serum-simultaneous' inoculation, which consisted of an infective dose of virus on one side of the body and a simultaneous injection of protective serum on the other. This was the method used by the Rinderpest Commission in 1917–18 mentioned earlier, and it was also used extensively in Kenya. This method produces a somewhat violent reaction, but it gives a lifelong immunity at a cost in mortality of 2–10 per cent. in some cases; in other instances, however, a much heavier toll was exacted. Its operation required the greatest care in the field, and one could seldom predict the results with certainty.

Anti-rinderpest vaccine.—Then followed the use of vaccine as an additional control measure. Anti-rinderpest vaccine is derived from the spleen and certain glands of a beast which is at the height of its reaction to a dose of rinderpest virus. These organs are pulped and mixed with glycerin and a small amount of formalin to give an inactivated 'glycerin vaccine', or instead of glycerin we may substitute normal saline solution to produce inactivated 'formal-saline vaccine'. The glycerin vaccine is more expensive, but remains potent for at least 4 months, whereas formal-saline vaccine, although cheaper, must be used within 14 days of its manufacture. This vaccine can be used by itself or in combination with virus. By itself it can be administered as a single, as a double, or as a triple injection at weekly intervals. A single injection of vaccine can be expected to give a protection for about 8 months. Two injections at a

week's interval would last rather longer and the triple vaccination should in most cases give a fairly solid immunity for about 15 months. This immunity can be kept up by the annual inoculation of a single dose of vaccine.

Goat-virus.—By 1938 another product began to emerge as the result of research work in the veterinary laboratories at Muktesar, India, and followed up by Daubney and Hudson at Kabete. This was goat-adapted virus. It was found that when rinderpest virus from bovines was passaged many times in succession through goats, in time a definite attentuation in the virulence of the virus set in, and this attenuated goat virus when inoculated into susceptible bovines produced a mild reaction and a fairly solid immunity to the original so-called ox virus. In the same year equipment was set up at Kabete Veterinary Laboratory by which this goat-virus was desiccated. Here was a tremendous advance on anything which we had in use heretofore. The cost of production was small, and as a result of the reduction in bulk following desiccation the expense of transporting this virus over the long distances in east Africa was very considerably curtailed.

It was not, however, until 1939 that this Kabete attenuated goat (K.A.G.) virus could be said to have passed beyond the experimental stage.

The foregoing substances, i.e. serum, vaccine, and K.A.G. virus, were the main foundations on which we built up our rinderpest-control measures, but there was one other consideration which must be mentioned, and that is the variation in the degree of susceptibility of the different types of cattle.

In Tanganyika we can define three distinct groups of bovines: (*a*) the short-horned Zebu which forms over 90 per cent. of our cattle; (*b*) the long-horned Ankole or Sanga which are limited to the western districts of Bukoba, Biharamulo, Kasulu, Kigoma, and Ufipa; and (*c*) the European breeds (chiefly Friesian, Ayrshire, and Red Poll) with their crosses on the zebu. I myself have again subdivided class (*a*) into the Highland Zebu and the Lowland or Plains Zebu, not on any anatomical difference but simply on their varying resistance to such diseases as rinderpest and tuberculosis. The Highland zebu is in my experience very susceptible to both these diseases, whereas the zebu of the Plains is not. However, other questions including environment enter into the matter, and I do not wish to pursue that subject here: but I do want to make it clear that the three groupings mentioned above require separate consideration when it comes to deciding what rinderpest-control measures should be adopted in their respective cases. For instance, serum made from the blood of zebu cattle affords practically no protection to an ankole, and vaccine of similar origin will reduce mortality only in a natural outbreak of rinderpest in ankoles from 80–90 per cent. down to 40–50 per cent. On the other hand, zebu serum and vaccine does produce a marked immunity in European and grade cattle, although the dosage has to be greatly increased.

The numbers of European and grade cattle in the area south of the Central Railway were very small, and great care was always taken to ensure that these valuable animals were immunized without loss.

The Rinderpest Campaign of 1938

Rinderpest had spread southwards and had reached the Ruaha river. A conference was held in Nairobi in February 1938 to discuss what action should be taken to protect the countries to the south, and it was recommended that the cattle to the south of the Ruaha between it and the Iringa escarpment should be triply vaccinated so as to produce an immune belt at least 40 miles deep, 'due attention being paid to the risk of the disease passing round the flanks of the belt'.

The Director of Veterinary Services, Tanganyika Territory (Mr. H. E. Hornby), lost no time in setting in motion the necessary measures to give effect to the resolution. Major Brassey-Edwards was placed in executive charge of the operations with five Veterinary Officers and an average of seven Stock Inspectors. It was found early on that rinderpest infection had crossed to the south side of the Ruaha river, and it was decided to strengthen the immune belt as originally planned by extending its depth southwards over the Iringa escarpment and to double-inoculate the area lying between the Iringa escarpment and the Ruaha river.

Operations began in May and were completed by November 1938. During this period reports were received of mortality in game in the 'fly' areas which marched on each side of the cattle zone. Greater kudu was the species mainly implicated, but carcasses of lesser kudu, bushbuck, eland, giraffe, bush-pig, and wart-hog were also found. In some areas kudu were almost exterminated and in one case 28 head of greater kudu were picked up by a Game Ranger along a stretch of not more than 4 miles of the Lukosi river near Iringa. By the end of 1938 the infection appeared to have died out in the game on both eastern and western flanks, and there was no known focus of rinderpest infection remaining in either cattle or game south of the Ruaha river.

During this campaign it was found necessary to set up a field laboratory for the production of vaccine. A total of 899 cattle was slaughtered for vaccine; 97,200 head of cattle received triple-vaccination, and in addition 51,800 were actively immunized. The mortality from the double-inoculation was estimated at 4·04 per cent. The only serious accident attending the vaccinations was the death of twelve cattle in one area. This apparently resulted from one container of vaccine having become contaminated locally with anaerobic pathogenic organisms. The total actual expenditure on the campaign was £5,363, and all was paid by Tanganyika Government.

In December 1938 Mr. Hornby was transferred on promotion to be Director of Tsetse Research and the writer was appointed to succeed him as Director of Veterinary Services, and in that capacity attended the second conference on rinderpest held at Nairobi in February 1939, at which the following two resolutions were passed unanimously:

Resolution No. 2:

'The Conference considers it essential that adequate staff should be made available to keep the area between the western fly-belt and the Northern Rhodesia and Nyasaland borders under close observation so long as any menace remains. Having regard

to the views expressed by the Director of Veterinary Services, Tanganyika Territory, the Conference notes that this would entail the maintenance of an intelligence service in this area which is estimated to cost in all (including existing staff) approximately £5,500 for a period of one year. The staff in the area should be brought up to the necessary strength without delay, and the Governments of territories to the south should be approached with reference to their willingness to provide the necessary financial assistance on the scale indicated in Appendix II to this Report.'

Resolution No. 3:

'In the event of an emergency arising from an outbreak of rinderpest in cattle south of the immunized zone, the Conference considers that immediate consultation should take place between the Directors of Veterinary Services of the Tanganyika Territory, Kenya, Northern Rhodesia, and Nyasaland, who should submit directly to the Governments represented at this Conference their recommendations for dealing with the emergency. Further, the Conference desires to assure the Government of the Tanganyika Territory of its unanimous support for such measures as, in the opinion of the Director of Veterinary Services, Tanganyika Territory, may be necessary to deal with the emergency by methods similar to those which have been adopted in 1938 with complete success so far as the limitation of spread through cattle is concerned.'

Unfortunately 1939 proved to be a critical year in more ways than one. International tension was making itself felt and matters like rinderpest control had to take a back seat, particularly in a country which contained many enemy subjects. Some of the departmental staff had to be withdrawn for emergency defence duties, so that the rinderpest intelligence service was able to function only in a haphazard manner. Nevertheless our scouts carried on, and in September 1939 reports of mortality in game in the Eastern Sector were received. These indicated that buffalo were dying in considerable numbers in the valley of the Kilombero river about 60 miles east of Iringa. Suspicions were also aroused as to the presence of rinderpest in the Western Sector where a few buffalo were reported to have died in the Saba River Game Reserve—just north of the chiefdom of Usangu (Mbeya district) with its 65,000 head of cattle. And in the following month (Oct. 1939) the infection had reached these Usangu herds. Thus the 1938 immunized belt had been outflanked and a situation had arisen which was fraught with the greatest danger. A series of conferences took place in accordance with Resolution No. 3 of the February 1939 conference, quoted above, ending with the meeting at Mbeya in January 1940, when it was decided to embark on a wholesale inoculation campaign with the object of immunizing every beast in the southern part of the Territory, beginning with triple vaccination in the most southerly (inter-territorial border) zone and in the more northerly district (Njombe and Iringa) by using the 'vaccine-virus' method, and in, the 1938 vaccinated belt (where some immunity, though waning, was still existent) with K.A.G. virus alone.

In the meantime whilst these conferences were in progress (Nov. 1939 to Jan. 1940) I decided to deal with the Usangu outbreak by inoculating all the cattle in that area with K.A.G. virus. Extra staff was drafted in, and the operations were pushed on in order that they should be completed before the rains broke at the end of the year. This was successfully

accomplished, but not before the disease had appeared in Rungwe district, near Tukuyu. This outbreak, however, proved to be only a small focus, which was promptly quarantined and suppressed by vaccination, but situated as it was about 40 miles from the Nyasaland border it gave rise to great anxiety.

At the same time (Nov. 1939) it was reported that rinderpest was present throughout Ufipa district and had probably been in existence for some time. This raised a very important issue, because if the report was true, it would mean that all our recommendations and measures would be futile, as the disease would have undoubtedly crossed the Northern Rhodesian border by now, and in view of the hundreds of miles of almost uninhabited 'fly' bush country, with great numbers of susceptible game extending from the Tanganyika border to the railway zone at Broken Hill and to the Zambesi river, we should have been faced with an almost uncontrollable situation in so far as the southern spread of rinderpest was concerned. I proceeded forthwith to the area and carried out some virus tests which resulted in 100 per cent. reactions and a mortality of 70 per cent., which proved quite conclusively that this report was without foundation.

It is of interest to compare the above mortality rate in the Ufipa ankole type of cattle following inoculation with K.A.G. virus with that in the plains-zebu of Usangu with approximately 10 per cent., and with that of a few test Highland zebus of Tukuyu where 75 per cent. succumbed.

Before describing the 1940 rinderpest campaign attention may be drawn to the phase through which rinderpest appeared to pass in game between the completion of the 1938 campaign (Nov. 1938) and Sept. 1939, when the disease reasserted itself in game in both eastern and western sectors. I have stated earlier that in our experience rinderpest soon died out in game unless the infection could be supported by a cattle link, and this contention is probably true in an area where the disease has been more or less enzootic for a period of years, such as over large parts of northern Tanganyika, but in the south of the Territory the disease had not been present for over ten years, and it can be assumed that the vast majority of the game was highly susceptible, and that therefore it was quite possible for the infection to be carried over vast distances depending on the density of the susceptible species of game. But under these circumstances it should not be difficult to detect the presence of rinderpest and to follow the trail. This was our experience in the Eastern Sector, where we were able to trace the course of the disease first in buffalo and later in greater kudu from the Kilombero valley to the Rufiji river, and thence to Kilwa (Sept. 1939 to March 1941). Our failure to detect the disease in the western zone between November 1938 and September 1939 can be ascribed not only to the dislocation of our intelligence service as the result of the international situation, but also to the fact that the service was not on a sufficiently large scale.

Other considerations must, however, be taken into account when dealing with the question of rinderpest control in game. For example, during the dry season the game are compelled to congregate around the permanent waters, and hence they are grouped so that if rinderpest is intro-

duced into a group it is likely to spread very quickly, but it is less likely to be carried from one group to another—particularly if the permanent waters are widely separated—in the dry season than in the wet season when rain ponds allow the animals to disperse at will. Again, shooting will tend to spread infection by causing the game to scatter in all directions, and for this reason it is always advisable to prohibit hunting in a rinderpest-infected area.

The Rinderpest Campaign of 1940

The Mbeya Conference (Jan. 1940) recommended:

(1) The triple vaccination of all cattle in southern Tanganyika from the Rhodesia–Nyasaland–Tanganyika border as far north as the 1938 vaccinated belt. This was modified later and the vaccine-virus method was used in Njombe and south Iringa districts to give a more permanent immunity.
(2) The re-immunization of the 1938 belt and all cattle north of it up to the Central Railway.
(3) The maintenance of an intensive intelligence system in both cattle and game areas.

It was hoped to complete the inoculations in 6 months and financial estimates were drawn up accordingly.

These recommendations were accepted by all Governments represented, i.e. Union of South Africa, Southern Rhodesia, Northern Rhodesia, High Commission Territories in South Africa, Nyasaland, Tanganyika, and Kenya. A sum of £55,000 was guaranteed by the southern states, but approximately £5,000 of this was reserved for a survey of the Luangwa Valley in Northern Rhodesia where buffalo were reported to be dying in considerable numbers. This survey was completed in February 1940. No trace of rinderpest could be found.

The staff (both professional and lay) for the inoculating units in the campaign was supplied in the main from the countries to the south and from Kenya. The intelligence service was composed of officers of the Tanganyika Game Department and the Veterinary Department supplemented by men recruited locally.

Mr. N. R. Reid, Veterinary Officer, was placed in executive charge of the whole campaign, whilst Mr. D. T. Mitchell was responsible for the production of the vaccine and all laboratory work. Mr. Reid established his headquarters at Mbeya, and a field laboratory was set up at Mbosi some 40 miles farther south. The Southern Rhodesian Air Force very kindly loaned a Gipsy-Moth aeroplane and pilot, which greatly facilitated communications over this huge area from the Indian Ocean to Lake Tanganyika, and it also enabled some game observation to be done speedily.

Operations began in mid-February 1940 and were completed by the end of September 1940. The inoculating service was divided into three units, roughly the South African, the Southern Rhodesian, and the Northern Rhodesian.

The work proceeded with remarkable speed and efficiency. The organization of stores, supplies of vaccine and virus and even of food in

the more remote areas, was well planned, particularly when it is borne in mind that in the early months of the campaign the weather conditions were very unfavourable. Continual rain made 'safari' and inoculation work a nightmare, and the indescribably wet and filthy conditions called for heroic efforts on the part of both field and laboratory staff.

In addition to these discomforts the intelligence service had to make and keep contact with the herds of game, a duty which requires courage and perseverance, more especially when dealing with sick game animals, which are often really dangerous.

An important factor facilitating the operations of the inoculating units was the efficiency with which the propaganda was 'put over' by the Administrative Officers and the resultant response by the native owners, who assisted by bringing in their cattle for treatment without hesitation, and there were very few attempts at evasion. It can therefore be assumed that by the time the inoculations had been completed there was a solid barrier of immunity in cattle placed between the infected areas north of the Central Railway and the countries to the south. (It should be mentioned here that the 20,000 cattle on the Northern Rhodesian side of the Tanganyika border and also some 40,000 head on the Nyasaland side had also received triple vaccination.)

A total of nearly one million head was treated and some 1,600,000 injections given. To produce the vaccine required 4,000 cattle were slaughtered at the field laboratory, Mbosi, where the staff were hard put to it to keep up supplies, and at one period 100 cattle were being killed daily for three days a week. It speaks volumes for the efficiency of the sterilization and general production technique that so very few ill-effects were experienced during the campaign.

This solid block of immunity would not of course last indefinitely. Indeed it was fully appreciated that the resistance engendered would begin to wane after about one year. Further, there were the young calves growing up which provided an ever-increasing amount of susceptible material. It was thus quite obvious that the intelligence service would have to be maintained for a considerable period after the termination of the campaign, and also that the passive immunity in the cattle would probably have to be reinforced later on.

In order to consider these problems advantage was taken of the visit of Mr. John Smith, Veterinary Adviser to the Secretary of State for the Colonies, to call a meeting of the Directors of Veterinary Services of the countries concerned at Dodoma in June 1940, and as a result the Secretary of State provided the sum of £32,000 per annum for two years from the Colonial Development and Welfare Fund from October 1, 1940, for the purposes mentioned.

In September and October 1940 the members of the inoculating units returned to their respective countries (the field laboratory at Mbosi had closed down in July), and the campaign was terminated. The intelligence service was incorporated within the Veterinary Department and from that time onwards the work was included as part of the normal departmental activities.

Rinderpest Position at the End of 1940

At the end of 1940 the only trace of rinderpest in either game or cattle south of the Central Railway that could be found was in an area some 80 miles south-west of the coastal town of Kilwa in the Eastern Sector. Here greater kudu were dying though not in large numbers. Mr. S. A. Evans, Senior Veterinary Research Officer, had made a definite diagnosis of rinderpest in the region in September 1940. This mortality continued spasmodically up to March 1941, since when no trace of the infection has been found in the Eastern Sector. The large herds of game animals on the Rovuma river, which forms the boundary between Tanganyika Territory and Portuguese East Africa, have been under continual observation and all remain healthy up to the time of writing (January 1942).

In May 1941, when it looked as if all rinderpest infection had disappeared from the southern half of the Territory, the writer put forward a suggestion that it appeared unnecessary to reinforce the immunity in the south-western area, and that the energy and funds would be spent to better advantage in attacking the disease north of the Central Railway and so preventing the reinfection of the south.

Reappearance of Rinderpest

In June (1941) a report was received of rinderpest in calves in a herd situated on the south-west corner of Lake Rukwa, and simultaneously carcasses of game animals, chiefly greater kudu, were found in the vicinity. The post-mortem lesions closely resembled those of rinderpest and later investigations confirmed this. All southern states were informed and a meeting was convened at Mbeya in July 1941 to examine the position, and it recommended that a game-proof fence be erected between the southern end of Lake Tanganyika and the north of Lake Nyasa thus closing the gap to any spread southwards between the great lakes. It was suggested that when this fence had been constructed all game within 25 miles of it on either side should be exterminated by systematic shooting, and that the fence itself should be patrolled by armed guards so that any break-through would be repaired without delay and any game within sight would be shot. The type of fence visualized was to be made of the local *miombo* timber to a height of 10 feet, and held in position by wire struts fastened to uprights every 6 ft. or so. The accompanying photograph will give some idea of the nature of the fence. This fence will not stop elephant, but should deter most of the other wild animals. The responsibility for the construction of the fence was undertaken by Northern Rhodesia and the cost was estimated at £30 a mile. The distance from lake to lake is approximately 220 miles. In January 1942, about 100 miles of this type of fencing has been completed over what was considered to be the most vulnerable portion of the inter-territorial border, and it is hoped that the remainder of the line will be completed as early as possible.

It should be mentioned that as soon as this new outbreak of rinderpest was found a game-proof fence of the type described above and about 25 miles long was thrown across the Saisi river valley at once, as this was

considered the most vulnerable part through which game might pass southwards.

At the same time all cattle which had been triply vaccinated in 1940 in the border areas, including Songea, were given an injection of K.A.G. virus: 200,000 head in all, and in addition the 60,000 head on the Rhodesian-Nyasaland side of the border were re-vaccinated. An outbreak of East Coast fever in central Ufipa district prevented the re-inoculation of the whole of that area, but the cattle in the Rhodesian border zone were immunized, so that there was little danger of spread of the disease through the agency of cattle.

To date, the reappearance of rinderpest in this area remains unexplained. It may be, of course, that the disease was carried by game in the ordinary way but that our intelligence system failed to detect it. I could accept this view if the disease had occurred over a period of a month or two, but we had had no reports of rinderpest in game in this area, and the nearest point at which infection had been known to occur was 60 miles east, where the disease was found in game about a year earlier, and had not recurred. Add to this the high susceptibility of the game in the area which would make detection still easier, and I feel justified in stating that this point of view is hardly reasonable.

At the Mbeya (July 1941) Conference I put forward the view that perhaps there existed a 'carrier' of the virus amongst the wild fauna (as is believed to exist in connexion with other virus diseases, e.g. horse-sickness, yellow fever, and equine encephalomyelitis) and that possibly the virus of rinderpest was modified or attenuated by passage through certain game animals. The meeting accepted the view that research on these matters was urgently needed and recommended that a programme be drawn up with this end in view. The help of a research worker from Onderstepoort with experience in such investigations was promised, and as a result Dr. A. D. Thomas, Veterinary Research Officer, and Mr. F. F. Kolbe, together with Mr. N. R. Reid, Veterinary Officer, Southern Highlands Province, carried out a brief preliminary survey of the west Lake Rukwa area in September–October 1941. The existence of rinderpest in game was confirmed and extensive infection was found in the greater kudu, buffalo, eland, topi, and reedbuck, and this epizootic continues.

The Rinderpest Position at the Close of 1941

South of the Central Railway the disease appears to have died out in the Eastern Sector and in the cattle-belt, and the only known focus of infection remaining is that in the game on the western side of Lake Rukwa, which constitutes a serious threat to Northern Rhodesia so long as the game fence remains uncompleted.

The cattle on both sides of the whole inter-territorial border zone have been immunized and little danger exists of spread by bovines. A full intelligence service is of course maintained in the southern area.

North of the Central Railway the disease has been pushed northwards and there is no known infection within a hundred miles of the railway, and active anti-rinderpest operations continue. The Eastern, Central,

Western, and Tanga provinces have been cleared together with most of the Northern province. To accomplish this 1,740,291 K.A.G. virus inoculations have been given in 1941. There remains the large, densely stocked areas of Usukuma and Musoma of the Lake province, with 1½ million cattle, and the Loliondo-Ngorongoro sub-district of Masailand in the Northern province, with about 250,000 head to be dealt with.

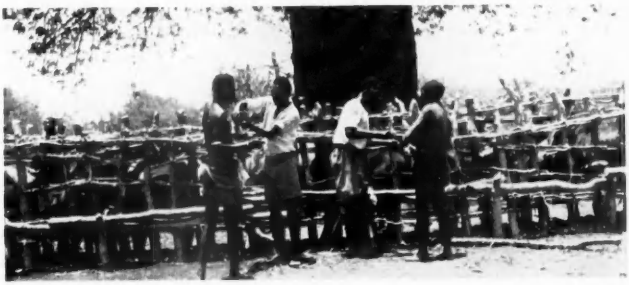
The Outlook.—If it were not for the game problem I would venture the opinion that rinderpest could be eradicated from Tanganyika Territory in the near future if the present scale of operations were continued, and, provided that similar measures were adopted in the contiguous countries of Belgian Ruanda-Urundi, Uganda, and Kenya, I think the position could be maintained.

In the meantime we must look to the research workers to assist us in solving the problem of rinderpest-spread in game and its control. It will be noted that all extensions of rinderpest in southern Tanganyika since 1938 have been caused by game, and it has taken 3 years for the disease to cover a distance of about 250 miles. Since that time control measures will have cost some £125,000 by September of this year, and we are not at the end by any means. This is the price to be paid for retrenchment and reversal of policy earlier.

(*Received March 14, 1942*)

Rinderpest: advanced skin lesions (stretothricosis) a common sequela of this disease and a useful symptom and aid to diagnosis

Game-proof fence



Inoculating cattle

FOOT-AND-MOUTH DISEASE AND ITS CONTROL IN GREAT BRITAIN

D. A. E. CABOT

Nature and virulence.—Foot-and-mouth disease is a systemic infection due to an ultravisible, filtrable virus to which ruminants and swine are susceptible. The period of incubation varies from 2 to 10 days, and occasionally even longer, when, towards its end, affected animals develop a high temperature, followed very soon by the appearance of vesicular eruptions in the mouth, on the feet about the coronet, and often on the teats in female animals. The mortality is usually low, but may be heavy among very young animals, and among ewes and lambs when an outbreak occurs during the lambing season.

The filtrable character of the causal agent was demonstrated in 1897, but more than 20 years elapsed before it was realized that more than one type of virus exists. Three in fact have been recognized. These different types are not identifiable clinically and, so far as is known at present, they differ only in their immunological character. In other words, a recovered animal cannot be reinfected with the same type of virus but will develop the disease again when infected for the first time by each of the other two types. The three types are known as O, A, and C: the first and second are reported to exist from time to time on the Continent of Europe, and the third is occasionally reported there. This difference in types accounts for successive waves of disease affecting the same animal population. All three types have been identified in outbreaks in Great Britain.

The disease is the most highly contagious of all animal plagues. An arresting example of its diffusibility is the epidemic, introduced from North Africa in 1937 into France, which spread eastwards as far as Scandinavia and Poland and also involved England. In Germany it reached its peak in 1938, when more than 666,000 farms were involved. Although the mortality is generally low the loss of condition, decreased milk yields, and sequelae leading to destruction of worthless animals entail heavy financial loss. As an example, the German authorities calculated that the 1937–8 epidemic caused losses in that country alone amounting to the equivalent of 83 millions sterling.

Control measures.—The methods of control of the disease may aim either at eradication or at minimizing its spread and the damage it produces. The choice of method will be dictated by local and general conditions, by the extent of infection in the country, by the risks of repeated reintroduction of infection, and especially by the position of the disease in neighbouring countries, particularly across land frontiers over which the constant traffic from an infected country presents a considerable danger.

In an insular country in which the disease is not endemic, measures can usually be applied to reduce the risks of introduction of the disease by prohibiting the importation from infected countries of susceptible animals, of hay and straw, and by controlling the importation of animal

products, including meat, and the disposal of dangerous materials, such as kitchen waste, which may be contaminated by infected meat-scraps and are largely fed to pigs. The risks involved in the importation of meat were exemplified in 1926 by a series of outbreaks in Scotland attributable to the introduction of pig carcasses from the Continent of Europe. Experiments subsequently carried out by the Foot-and-Mouth Disease Research Committee showed that the virus can survive at low temperatures under trade conditions in the carcasses of infected animals for 3 months and even longer.

Measures are in force in Great Britain to eliminate some of the risks of introduction of infection and to reduce other risks, the complete elimination of which is impracticable. When, despite the precautions taken, disease appears—and the history of some of the initial outbreaks in Great Britain suggests that infection can be introduced there by uncontrollable means—immediate steps are taken to extinguish the foci of infection and to prevent its spread. This is the policy also adopted in Northern Ireland, in Eire, in the United States of America, and has also been attempted under different and more difficult conditions, with varying success, in continental countries, for example in Switzerland, Denmark, and Sweden.

On the occurrence of disease, simultaneous action is taken with two objectives: (1) to eradicate infection and prevent its spread from the known centre or centres of disease, and (2) to overtake the movements of dangerous animals, or of persons or materials from such centres before notification of suspected disease was made, and to control generally the movement of live stock in the district.

On the infected farm, immediately after the diagnosis has been confirmed by head-quarters on telephonic report, valuation of the stock is carried out by an expert valuer, and the slaughter of the animals is promptly put in hand in order to prevent the creation of more virus as individual animals successively develop the disease. A preliminary disinfection of the more heavily contaminated parts of the buildings or yards is made to destroy gross infection. Usually, slaughter is completed within 24 hours of diagnosis. It is the rule to use mechanical killers.

Disposal of carcasses.—Two alternative methods of disposal of carcasses are available, burning or burial. The former is usually adopted, but in exceptional cases, resort is had to burial. A proportion of the carcasses may be salvaged for human consumption, but care must be taken that the animals, the meat of which it is proposed to salvage, are clinically healthy and are not in an infective stage of the disease. Therefore only animals free from lesions and the temperature of which is normal at the time of slaughter are reserved for salvage. The special arrangements involved in salvage such as the bringing in of butchers, preparations for hanging the meat to allow it to cool, &c., are expeditiously made on the farm and do not appreciably delay the completion of slaughter. When the carcasses have been dealt with, a thorough disinfection of byres, yards, styes, and other parts of farm-buildings is carried out, but pastures are left to the action of natural forces. A cheap and effective agent for disinfection is washing soda, in the dilution of 4 per cent., i.e. approximately 6 oz. of washing soda to a gallon of water. Special atten-

tion is required in the handling of contaminated foodstuffs and straw. Some may be destroyed by burning or burial, but fumigation (1 lb. of potassium permanganate and 1 lb. of formalin (40 per cent. formaldehyde solution) for 10 hours in an air-tight building is frequently adopted.

Inspectors and all workers on infected premises are clad in overalls; the farm workers are employed in the cleansing and disinfection of the premises in order to limit the number of strangers brought on to the infected farm. The clothes worn by attendants on the stock when the outbreak was discovered are washed or sterilized.

Four weeks after completion of disinfection the premises may safely be re-stocked.

Prevention of spreading.—General measures are put in hand at the earliest moment. Before the visiting veterinary inspector has reported to head-quarters, he has already signed a certificate the effect of which is to prohibit movement of stock within a radius of 5 miles of the location of the suspected outbreak and the police, notified to this effect, give the necessary warning and, if necessary, hold animals assembled at a market in the district. On confirmation of the disease, the certificate is amended and the area involved is now of 15 miles' radius. In a few hours, the formal Infected Area Order with its geographical definition of the area—approximately of a radius of 15 miles—is issued. The early action taken on the strength of the certificate is often most valuable in preventing movement of stock. The general effect of the order is to prevent movement of cattle, sheep, and swine without a licence; to close markets except for the sale of fat stock for slaughter, and to detain for 14 days animals (except fat) moved by licence. Permissible movements are either into the area from outside, or within the area, but movements from within to destinations outside are not authorized.

On rare occasions, where a series of markets has become involved or when a potentially dangerous situation has otherwise arisen, restrictions are imposed upon a much wider area, and, in fact, it has even been necessary to restrict the movement of live stock over the whole of Great Britain by the declaration of an order very similar in its effects to the Infected Areas Order, the principal purpose, in these exceptional cases, being to close markets to store stock. Such extensive areas are usually in force for 14 days only, as the disease will have manifested itself during this time among the infected animals, and where this has occurred, local Infected Areas Orders have been applied.

But whilst the Infected Areas Order controls the movement of stock generally, much remains to be done in certain directions, and to be effective must be done promptly. Animals brought to the infected farm or moved from it before the declaration of disease, movements of persons to and from the premises, removals of materials, milk-churns, sacks, &c., must all be traced, the necessary action taken, and any stock involved on other premises kept under observation. Vehicles, motor lorries, or railway trucks used in the transport of suspected animals or materials must be traced and disinfected. Search must be made for a possible hidden centre of infection. Stock on farms in the immediate vicinity of the outbreak must be kept under daily observation. It is the

common practice to slaughter individual animals removed at a dangerous time from an infected farm in order to save the rest of the herds to which they have been admitted, and although occasionally in spite of this action the disease breaks out in the course of a few days, there is no doubt that many herds have been saved by this sacrifice of individual animals.

Conclusion.—Such has been the policy and practice in Great Britain for many years: the prohibition or control of means of introduction as far as is practicable, and the prompt application of repressive measures when the barriers have been penetrated. Success can only be achieved by the loyal co-operation of the agricultural community, by early notification of suspected cases, by enforcement of the regulations by the local authorities and by the police, by the assistance of transport organizations, and by auctioneers in promptly supplying lists of buyers and sellers in stock markets where necessary. This collaboration has always been assured to the central authority, which for this particular purpose maintains at head-quarters a day-and-night service to enable the machinery to be set in motion at any moment.

These measures have prevented the disease from establishing itself in Great Britain. Elsewhere countries have been overrun in spite of restrictions on movement of animals, supervision of infected farms, and the application of palliatives, sometimes hyper-immune serum, sometimes convalescent serum. Recently methods of vaccination have been introduced.

There is no middle course: either the disease must be suppressed by rigorous action or, in spite of palliatives, it will become endemic, and a burden on the national economy.

(*Received July 4, 1942*)

THE WILD *ARABICA* COFFEE ON THE BOMA PLATEAU, ANGLO-EGYPTIAN SUDAN

A. S. THOMAS

(*Economic Botanist, Department of Agriculture, Kampala, Uganda*)

THE Boma plateau is situated near the south-eastern corner of the Anglo-Egyptian Sudan, not far from the boundaries with Abyssinia and Kenya; the centre lies about 6° 10′ N. and 34° 80′ E. The plateau consists of a few square miles of land at an altitude of 3,500 ft. or more, and forms the highest part of a ridge of hills, about 100 miles long, running north and south. On the west side of the plateau is an escarpment, the ground falling steeply down to the plain at a level of about 1,500 ft.; on the east side there is a gentle slope down to the wide valley separating the Boma plateau from the Abyssinian highlands. Several hills arise out of the plateau, the largest being Nelichu and Bejunu, both of which are nearly 6,000 ft. high.

The Boma plateau is unique in that it is the only place outside Abyssinia where wild *Coffea arabica* L. is known to grow; its occurrence there was reported only a few years ago [1]. Dr. J. G. Myers, Ecological Adviser to the Sudan Government, visited the plateau in 1938 and kindly arranged that I might accompany him on a second visit in December 1941, for, after he had described to me how the coffee grew in the forest, I was anxious to see the plants and to collect seed for breeding purposes.

Most of the plateau was covered with grass-land; on all the drier slopes *Loudetia arundinacea* Steud. was dominant and in the more sheltered, moister valleys *Hyparrhenia diplandra* Stapf, *Hyparrhenia cymbaria* Stapf, and *Beckeropsis uniseta* K. Schum. were common. Scattered trees of *Vitex cuneata* Thonn., *Ficus* spp., *Combretum* spp., and *Terminalia* spp. were common in the grass-land and were abundant in the gullies and on the edges of cliffs. In some of the valleys and on some of the steeper slopes there were patches of dense, closed forest, the largest areas being on the northern and western faces of Nelichu and in the valleys to the south and east of the hill. Visits were paid to two localities on the slopes of Nelichu where wild *arabica* coffee is abundant —to Barbuk on the north and to Rume on the south.

The Barbuk area.—At Barbuk there was a large area of closed forest at an altitude of about 4,700 ft. The forest was dense, with an even canopy of large trees—*Aningeria altissima* (A. Chev.) Aubr. and Pellegr., *Olea welwitschii* (Knobl.) Gilg. and Schellenb., *Celtis* sp., *Mimusops* sp., and *Manilkara* sp., the last apparently the most numerous tree in the forest. Lianes were abundant. There was a thick undergrowth of shrubs: *Argomuellera macrophylla* Pax. and *Dracaena fragrans* (L.) Ker. Gawl. were codominants, whilst *Rinorea ilicifolia* (Welw.) O. Ktze. and *Whitfieldia elongata* (Beauv.) C.B.—Cl. were abundant. The forest grasses *Leptaspis cochleata* Thwaites and *Oplismenus hirtellus* P. Beauv. were prominent among the herbs.

Coffea arabica was locally frequent, growing as a small tree with the crown above the shrubby undergrowth; most specimens had a single upright stem crowned with a mass of primary branches; some trees had one or two upright branches. The largest tree seen was about 18 ft. high; the circumference of the trunk was over 7 in. just above ground-level and over 6 in. at the height of 1 ft. above ground. The bark was smooth, pale brown, with a slight incrustation of moss.

The root-system of one large specimen was investigated. In the top 2 in. of soil there was a mass of fine feeding-roots, many of them being right on the surface, below the thin covering of fallen leaves. When the soil was carefully scraped away, a system of well-developed lateral roots was exposed, arising just below ground-level and spreading horizontally.

Most of the older trees had a bare trunk to a height of about 8 ft., for the lower primary branches had fallen off. The trunks were whippy and could be bent over to pick the fruit, but in some cases the trees had been cut off by the local Kichepo tribe who gather the fruit. The primary branches were up to 3 ft. long; the amount of secondary branching varied on different trees.

As might have been expected under such a dense canopy of shade, the leaves were large and dark green. The colour of the young leaves varied from copper to green and the size of the leaves seemed to vary from tree to tree, but it was impossible to assess how much of the variation was due to genetic factors and how much to differences in light intensity. The leaves along one side of each of four primary branches on a single tree measured (in inches):

Primary 1. 7, 5½, 4, 5, 6½, 6½, 6½.
Primary 2. 7½, 7½, 8½, 3½, 6¾, 7, 6¾, 5½, 7¼, 7½, 7¾, 7½.
Primary 3. 6½, 7½, 1¼, 7¼, 7, 7¾, 7, 6¼.
Primary 4. 6, 8, 5¾, 6¾, 8½, 6¼, 5½, 8, 7¼.

When so great variation was found on a single tree, it was obvious that it would be difficult to utilize leaf-characters as a means of classifying the wild coffee into varieties.

There was marked variation in the fruit also: on some trees it was small and on others it was very large; most of the cherries were long and dark red, but some were broad and pale, even when ripe. Unfortunately there was not much crop on the trees; most of them were bearing only a few green or ripe fruits, some none at all, and it seemed that much of the crop had been gathered.

Many young seedlings were springing up near the larger trees and plants of all ages could be found. Young plants were noticed beside the path just inside the edge of the forest; probably they had arisen from fruit dropped by the Kichepo after they had been picking from the wild trees.

The Rume area.—Rume is a valley on the south slope of Nelichu and, as the crow flies, it is only 2 or 3 miles away from Barbuk. The sides of the valley are rocky and steep, but the bottom is flat and lies at an altitude of about 4,100 ft. Until four or five years ago the valley had been filled with forest, but since the Italian invasion of Abyssinia much clearing and settlement had taken place. At the time of our visit many large

trees remained; some had been killed by fire but remained standing; some had fallen but had not yet rotted; others were still alive. The living trees included *Antiaris toxicaria* (Rump. ex Pers.) Lesch., *Ficus* spp., and *Manilkara* sp., and it seemed that in this forest, as at Barbuk, the Manilkara had been the dominant tree. Most probably the forest had been dense like that at Barbuk, for, although most of the undergrowth had been cleared, yet one or two plants of *Rinorea ilicifolia*, a species typical of closed forest, were still persisting.

After clearing, the land had been planted with maize which, together with considerable amounts of a small-leaved tobacco, covered the valley floor. Some sorghum also was growing as, in places where the soil fertility had been depleted by two or three crops of maize, this crop was sown by the Kichepo.

Standing out dark among the ripening maize were scattered bushes of *Coffea arabica*, either singly or in groups. We were told that none of these bushes had been planted and that they were all relicts of the original undergrowth of the forest, retained when the other species were cut and burnt. Examination of the stems showed that some of the bushes were of great age—the circumference of the largest trunk was 11 in. at 1 ft. above ground-level.

In one patch near the north side of the valley, the coffee bushes still retained their original stems, which were 15 ft. long; but instead of being erect, as in the forest, these stems had bent over and given rise to many erect branches. In most cases, however, the original trunks had been cut off and the bushes had produced about 6 or 8 stems from near ground-level.

As in the case of the coffee at Barbuk, the typical root-system consisted of well-developed lateral roots radiating just below the surface of the soil; in some cases these roots were exposed by soil wash. Young trees and seedlings were springing up beneath and near to the older specimens, but it was affirmed that the Kichepo had not planted any of the coffee in this valley. On his previous visit Dr. Myers had seen some coffee farther south which seemed to have been planted.

The bushes at Rume were up to 8 ft. in height—a few were taller. They varied in habit, but most were dense in growth, having a mass of primary branches up to 3 ft. long; the amount of secondary branching differed from bush to bush. The leaves were dark green with a dull surface and were smaller than those of the coffee in the forest at Barbuk, as is shown by the length in inches of the leaves of three primary branches of a typical bush:

Primary 1. 4, 3¾, 4, 5¾, 4½, 5¼, 4½.
Primary 2. 2½, 3, 4½, 4, 5¼, 4¼, 5, 3½.
Primary 3. 4½, 6, 4½, 5½, 5¾, 5, 5, 4.

Not only were the leaves shorter than those of the coffee at Barbuk, but they were also considerably narrower in proportion to their length. These differences may be attributed mainly to the effect of exposure, but there is no doubt that the Rume coffee was of a different type from that at Barbuk, for at Rume all the bushes seemed to be green-tipped, whilst at Barbuk many bushes were copper-tipped.

Unfortunately the crop was nearly over and it had been gathered from some of the best groups of bushes. Other bushes were still bearing ripe cherry; a few individual shrubs had produced fruit nearly as large as that of the Barbuk coffee, but most were bearing smaller fruit. It was impossible to ascertain how much of the disparity in size was due to genetic characters, and how much was due to the effects of exposure and of the magnitude of the crop, for fruiting was much heavier than in the forest at Barbuk.

As much fruit as possible was collected and the seed was carefully prepared. Some has been sent to the East African Agricultural Research Station, Amani, some to the Coffee Research Station, Lyamungu, and some to the Scott Laboratories, Nairobi. The remainder will be grown at various stations in Uganda. As the crops were nearly over, the amount of seed available was much smaller than was desired, but it is hoped that it may give rise to types valuable in cultivation. The Barbuk coffee had a very bold bean and the Rume coffee was growing well at a relatively low elevation.

Even when allowance was made for the fact that the Boma plateau is 6° N. of the equator, the altitude at which the coffee was growing was lower than had been expected. *Coffea arabica* has been grown in Uganda for over forty years, but no locality is known in which this species has become naturalized on any considerable scale, although many of our forests contain an abundance of the same shrubs and grasses as were associated with the wild coffee at Barbuk. It is possible, therefore, that the strains of coffee from the Boma plateau will prove more suited to altitudes of about 4,000 ft. than any of the strains now cultivated in the protectorate. New strains of this character would be of great value.

Soils.—Many of the areas in East Africa where *arabica* coffee is most successfully cultivated have soils derived from volcanic rocks, and it is interesting to note that the Boma plateau, where the coffee grows wild, also is built up of igneous rocks.

There is an increasing volume of evidence that the supply of bases in the soil may be a limiting factor to the successful cultivation of *arabica* coffee. Most of the best estates in south India are on alkaline soil; in Hawaii spectacular increases of crop have been produced by potash manuring; and in the Kigezi district of Uganda the condition of *arabica* coffee growing on poor acid soil has been much improved by the application of wood ashes around the base of the bushes.

It had been expected, therefore, that the soils of the Boma Plateau where *arabica* coffee was growing wild would prove to be neutral or alkaline. Small composite samples of soil were taken at a depth of about 2 in. where, as mentioned above, there appeared to be the greatest development of fine feeding-roots; these samples were tested for reaction by B.D.H. Universal Indicator and for available phosphate, potash, and lime by Spurway's methods [2]. Two samples from the forest at Barbuk had a pH value of about 6·0 and 6·5; the soils were chocolate-coloured friable loams and were low in phosphate but fairly well supplied with potash and lime. Four samples in the clearing at Rume were taken, all from under groups of coffee bushes, where there had been no fires

when the undergrowth had been burnt. These samples varied greatly in reaction, the pH values being about 5·0, 6·5, 8·0, and 7·5. The first was from a patch of coffee beginning to go yellow: the soil was a bright red friable loam, poor in bases—it seemed to have been leached by exposure. The second was darker and was fairly well supplied in bases: the coffee also was in better health. The third and fourth were from large groups of healthy old coffee: the soils were brown in colour and rich in bases. None of the Rume soils was rich in phosphates.

It would be very interesting to visit Rume after the bushes and the soil have been exposed to sunlight for a few more years, in order to study the effect on the health of the coffee. At the time of our visit the soil still retained much of its original fertility, but there is no doubt that after a few years the fertility will fall off and the coffee will suffer. Incidentally, no Coffee Leaf Disease (*Hemileia vastatrix*) was noticed on the less healthy coffee at Rume, although the disease usually appears on debilitated coffee in Uganda; but, as the intensity of attack varies greatly according to the season, the disease may have been present in small amounts.

Origin.—The *arabica* coffee on the Boma plateau is growing wild and reproducing itself without human aid, yet it is possible that it is not truly indigenous and has been introduced in the distant past from the main mass of the Abyssinian highlands, of which the plateau is an outlier. The forest at Barbuk (and most probably the forest at Rume had been of a similar type) was dense; but it contained many quick-growing trees, it had an uneven canopy, and there was a rich growth of lianes and shrubs—all indications that it was not a climax forest. On the more rocky, steeper slopes of Nelichu another type of forest occurred in which a leguminous tree (probably a species of *Baphiopsis*) formed almost a pure stand with a dense even canopy and little undergrowth, and this seemed to be a climax forest. No large specimens of *Coffea arabica* were seen in this *Baphiopsis* forest, only a few young seedlings beside the path.

The sites where *Coffea arabica* was growing therefore might have been cultivated in the distant past, and the coffee might have been brought from Abyssinia. The coffee at Rume seemed of a type distinct from that at Barbuk and, although in both places there was considerable variation between individual trees, yet the range of forms was not nearly so wide as in the plants raised from seed sent from Maji in south-west Abyssinia by the British Consul in 1936. This coffee had been collected in the Geisha district about 25 miles north of Maji.

The conical mountain Siski, close to Maji, could be clearly seen from the eastern slopes of Nelichu, for it was only about 75 miles away in a straight line; farther north lay the dim mass of the Abyssinian highlands, including Geisha mountain. But the valley between was low and was covered with open woodland in which *Coffea arabica* would not grow; most probably the coffee had been brought to the Boma plateau by birds, by mammals, or by man. The types of coffee collected on this visit show promise of being useful in breeding work, in spite of their restricted range of variation. It is certain that on the Abyssinian high-

lands, the main centre of wild *arabica* coffee, there must be a much wider range of forms, whose potential value in coffee selection is very great.

Acknowledgements.—Grateful acknowledgement is made of the kindness of the civil and military authorities in granting me facilities for my visit, and of all the help and hospitality extended to me by civil and military officers, and especially by Dr. Myers.

REFERENCES

1. A. Chevalier, Les Caféiers du Globe, 1929, p. 73.
2. C. H. Spurway, Soil Testing. Michigan State Coll. Agric. Expt. Stat., 1938, Tech. Bull. No. 132.

(*Received May 23, 1942*)

IMPROVEMENT IN QUALITY OF AUSTRALIAN BUTTER EXPORTED TO THE UNITED KINGDOM

F. WIGAN

(*Commonwealth Supervisor of Dairy Exports*)

IT has been stated by some of our friends in the United Kingdom that one of the most striking achievements in modern agriculture has been the great improvement in the quality of Australian butter being marketed in London over the last four or five years. To explain all the details and developments contributing to the high quality of Australian butter would require much more time and space than can be given in a short account, but perhaps the following condensed statement may serve to indicate the methods by which this improvement has been effected.

The dairying industry began its commercial life in Australia in the early 1880's, and has grown to be the second most important primary industry in the Commonwealth to-day, and it is confidently expected that its importance to the welfare of the country will increase still more.

Naturally, the dairy farmers of those early days were for the most part untrained in dairying, and many of those occupied in dairying to-day have also lacked this education. The ordinary methods of production and manufacture as known in older countries were copied and practised throughout Australia, but Australia's geographical and climatic conditions were so vastly different from those of other countries that the pioneers of the industry had to contend with many problems not encountered elsewhere. However, through the resource and initiative of the dairy farmers and butter-factory managers the industry developed slowly, but with the introduction of more scientific methods, including refrigeration in factories and cold storage on ships to carry the dairy produce overseas, its expansion became rapid. The introduction of the home cream-separator into the dairy farms about the same time was perhaps the greatest cause of this rapid expansion by enabling farmers to take up dairying even when situated many miles from a manufacturing centre. This development, however, created a major problem due to the infrequent delivery of cream to the factories in districts where the roads were bad and the farms were far from the factories. Such cream deteriorated considerably, and the great difficulty was to produce butter which would keep its quality when marketed 12,000 miles away in the United Kingdom. This problem caused many factories to use a preservative, such as boracic acid, to mix into the butter at the time it was manufactured, especially for export, and to a certain extent this preservative did help the butter to arrive in London in better condition.

The Governments of the principal States in the Commonwealth established dairy branches in their Departments of Agriculture, to which they appointed the most competent men to assist producers and manufacturers to obtain more butter-fat per cow and to produce a higher quality butter. As there appeared to be an unlimited market overseas

for Australian butter, expansion of the industry was still further encouraged.

The Commonwealth Government, in 1917, realized the vast importance of the dairying industry, and established the Commonwealth Dairy Inspection Branch to which Commonwealth officers were appointed to check the purity and quality of the dairy produce exported from Australia in order that the country's good name for high-quality produce and honesty should be preserved, and also to have one uniform standard and system of examining the produce in all States of the Commonwealth prior to exportation. The quantity of butter being exported about that time had become very considerable because many people had taken up dairy-farming owing to the high prices obtained for butter during and after the last world war. With the introduction of grass-land improvement, top-dressing of pastures, and better farm management, the production of butter in Australia almost doubled itself in about three years by the year 1932–3, and the total butter examined and passed for export by Commonwealth grading officers increased to 4,206,440 boxes for that year, compared with 2,168,869 boxes for the year ending June 30, 1930. Much of this butter was not of a high standard, and although preservative was added to it, much of it did not have that essential keeping-quality necessary to give confidence to buyers in the United Kingdom. Some of the more progressive manufacturers had, however, already learned of and adopted the practices of neutralizing and pasteurizing cream as a new and improved method of making butter, and with excellent results.

Some of these progressive manufacturers had discontinued the use of preservative substances in butter some years before 1928, the year that the U.K. Government prohibited the importation of butter containing any preservative, and had demonstrated that neutralization and pasteurization of the cream ensured much better keeping-quality than any added preservative.

In 1927 the Commonwealth Government decided to send to London an Australian Dairy Expert, whose chief duty would be to report upon the quality of Australian dairy produce on the U.K. markets, and to advise ways and means of improving not only the quality but also the packing and presentation of the produce, and to get first-hand information of buyers' requirements. The stationing of this officer in London at the end of 1927 enabled him to give accurate reports of the quality of Australian butter as it arrived, but unfortunately much of it was not of a good quality, especially that from factories which had not perfected their manufacturing methods sufficiently to enable them to make a good keeping-quality butter without the aid of preservatives. I had the good fortune to be the first Dairy Officer appointed to London to undertake the duties of examining Australian dairy produce, and I shall never forget some of my experiences of quality-defects brought to my notice by importers immediately upon my arrival. Many of the butters which had been graded 'choicest' in Australia were only of first and second quality. The defective flavours noted included the following: unclean, stale, fermented, cheesy, and in some instances fishy. In some ship-

ments more than half the 'choicest' butter had deteriorated. Importers were emphatic that the butter must have keeping-quality for any reliance to be placed on Australian gradings. We had to establish the confidence of buyers in our produce, and so the problem of improving the quality and keeping-quality of our butters became a matter of major concern to all interested in the Australian dairying industry, to the Commonwealth and State Governments, and especially to the manufacturers of the butter; but it was not till about four years ago that the Ministers of Agriculture at an Agricultural Council meeting agreed that special efforts should be made to improve the quality of Australian butter generally, in co-operation with Commonwealth dairy officers and butter-factory managers and dairy farmers. This work is still in progress. Copies of the gradings of export butter by Commonwealth officials were forwarded daily to the butter factories concerned and to the State Departments of Agriculture. The remarks on these grading certificates indicated defects in flavour, texture, and condition of the butter, and so enabled manufacturers to take immediate action to remedy them or seek the assistance of department officials. The Commonwealth grading standard has been fixed on the basis of commercial requirements, with a scientific background to ensure a uniform standard-quality butter with dependable keeping-quality.

The butter exported to the United Kingdom is packed in boxes bearing brands denoting the quality of the butter contained in each box. The choicest or highest quality butter is packed in the Australia brand box with the impression of a Kangaroo in the top right-hand corner as evidence that the butter has been classified as 'choicest' quality by the Commonwealth grader in Australia prior to export. This classification of the butter has become so accurate that in the last two years over 90 per cent. of the butter graded 'choicest' in Australia was choicest quality upon delivery in London. The figures are: 93·7 per cent. for the 12 months ending 30/6/38, and 94·3 per cent. for the 12 months ending 30/6/39. This is an accomplishment of which any country could justly be proud, and indicates what great improvement in quality has taken place since 1928, when not 50 per cent. of our 'choicest' butter retained its quality upon arrival in the United Kingdom.

The line of attack in this problem was to improve the cream delivered at the factory, to re-model factories on up-to-date lines, to construct new, modern factories and equip them with the best machinery, pay the strictest attention to hygiene, and utilize methods of manufacture that experience had proved to be the best for Australia.

The improvement of cream-quality called for the education of dairy farmers in dairy hygiene, which was undertaken by the State dairy officers. This, together with delivery of the cream more frequently to the factory before it had time to spoil, made possible by the introduction of high speed motor-trucks and the improvements to country roads, has resulted in a cream of better quality being delivered to the factories.

In the last few years some millions of pounds sterling have been spent on improving and building new factories throughout the Commonwealth, whilst the employment of fully qualified cream graders has been made

compulsory in all butter factories. Competition for cream supplies between factories, and in many instances between co-operative factories, has helped to retard improvement in quality; factories have returned to the farmers choicest quality prices for inferior quality cream, thereby encouraging the farmer to continue the supplying of an inferior article. In some districts this problem has been overcome, and when it has been overcome in all districts a big improvement in quality will automatically follow.

There has also been a move towards the supply of cream daily to the factories, and that one feature alone is contributing largely to recent improvement. The problem has, however, been to make good butter out of the cream, infrequently delivered, and therefore to some extent deteriorated, and it is in this respect that scientific methods have been brought to the aid of the butter manufacturer. Realizing the great value to butter-makers of systematic scientific aid and knowledge, some of the larger combinations of factories have appointed a dairy technologist to carry out daily examinations of their butters, chemically and bacteriologically, as a means of discovering causes of quality defects and manufacturing irregularities. These services have paid the factories well and have considerably helped to improve the quality in the last three years. The officers attached to these services come to the butter-grading floors, where they draw samples of the butter for examination and consult with the Commonwealth graders regularly. In this way scientific and practical information are harnessed together for the benefit of the industry.

The manufacturing methods employed greatly influence the ultimate quality of the butter made from all classes of cream received at the factories, and in most instances improved methods demand improved equipment. In this respect Australia has been most fortunate in the class of manufacturer who has undertaken not only to manufacture this equipment, but in many instances has invented and produced a completely new type of equipment. In fact, Australian manufacturers of dairy equipment are now exporting to many other countries of the world, and hold patent rights for some of this equipment. Scientific research has shown that inferior metal equipment was frequently responsible for quality deterioration, and to-day the factories of Australia are equipped throughout either with stainless-steel or glass-enamel plant. In many factories the churn is the only wooden implement in use; many have now changed to the all-metal churn, which, it is claimed, can be fully sterilized after each using.

This perfecting of the equipment would be of little avail if the factories allowed careless and unhygienic methods to prevail during manufacture, and in this respect the dairy technologists have contributed largely to the education of dairy operatives.

When cream of uncertain age and quality arrives at the factory, it must be scientifically treated, even after classification by expert cream graders, and the greatest aid to improving quality in the factory has proved to be the manufacturing process known as neutralization and pasteurization of the cream. Australia has sadly felt the need of dairy

research in matters such as these, but after years of research I think it can be claimed that Australian manufacturers have obtained the best results possible by these processes.

Standardization of the fat-content of the cream before neutralization is general practice, thereby ensuring an easy flow and thorough mixing of the cream, so that the full degree of neutralization and complete pasteurization can be effected with the least injury to the butter-fat itself. Efficient neutralization has removed one major cause of deterioration during storage, namely, acidity in the butter, whilst pasteurization has helped eliminate objectionable food flavours, and definitely assured a high degree of keeping-quality in the butter, provided contamination of the cream or butter has not been allowed to take place subsequently.

The degree of acidity to which the cream should be reduced for best results depends first on the acidity of the original cream; in practice the acidity of the neutralized cream is somewhere between 0·05 and 0·08 at the time of churning. The growing practice of supplying the cream to factories daily has lessened the problems associated with neutralization, and standardizing the fat-content of the cream to about 35 per cent. has been found essential to avoid defects developing from the neutralizing and pasteurizing processes.

The first system of pasteurization of cream was the 'holder' system, heating the cream at 145° to 150° F. for about half an hour. This gave way to the 'flash' system of pasteurization, using temperatures ranging from 190° to 200° F. with a continuous flow of cream through the plant. In recent years a system of pasteurization using live steam and a partial vacuum, which was originated in New Zealand and known as the Vacreator system, has been adopted in many factories, whilst other factories have adopted a similar Australian live-steam and vacuum pasteurization, viz. the 'volatilizer' system. It is claimed that both these systems considerably reduce taints in flavour and bring about a more complete pasteurization of the cream. Both systems, if used according to the makers' instructions, effect the highest degree of pasteurization and are giving excellent results.

In order to assist in the general improvement in quality, dairy officers of the State Departments of Agriculture visit butter factories throughout the year, inspecting the premises and equipment to ensure that efficiency and the fullest sanitary conditions exist therein, and to impart the latest scientific knowledge and guidance to factory operators. This service has had excellent results in the last few years and a readily noticeable evidence of its success to the everyday purchaser of butter is the almost perfect texture of nearly all the butter manufactured in Australia to-day.

Visits by factory managers to premises where export butter is graded and where they can discuss quality defects and remedies with the Commonwealth graders have materially helped factories to improve their manufacturing methods and the ultimate quality of the butter, and obtain a better understanding of what is required by the export trade.

The problem of still further improving butter quality is mostly one for dairy farmers, as it depends largely on supplying a better quality cream to the butter factories, and so reduce the large quantity of

inferior cream that was formerly supplied to them in a number of districts. There is plenty of scope for the farmers' energies in this direction, calling for a full knowledge of general dairy hygiene and its strict and unstinted application. The correct cream-grading by all factories and the helpful assistance of State dairy field officers, dairy technologists, and others would work wonders in improving butter quality, and I feel confident that the full co-operation of all concerned would result in a still further big improvement in the quality of Australian butter placed on the United Kingdom market; and when that has been accomplished Australia will merit a repetition of the praise that has been so liberally accorded to us for our recent improvement in quality of butter on that market.

(*Received August 25, 1941*)

GRASS-BURNING

D. C. EDWARDS

(*Department of Agriculture, Kenya*)

GRASS-BURNING is a very old native practice throughout East Africa; it is still very common, and some European farmers also use it. Of late, the controversy concerning its value has flared up again following the world-wide prominence given to soil erosion. Advocates of grass-burning claim that it is needed to maintain natural pasture in a state fit for grazing; the opponents aver that it causes soil deterioration. The former base their opinion on the experience of natives and of practical farmers; the latter on general principles and views expressed in other countries. There is no rigorous scientific evidence to support either side.

In Kenya, fire has been and still is in fairly general use where the rainfall favours the accumulation of old growth of herbage under the prevalent conditions of light grazing. Several major zones of vegetation are involved, from the moist Mountain Forest region to the comparatively dry Acacia–Tall Grass Savannah [1], where the practice is most common. Apart from the vast semi-desert areas occupying the northern and eastern portions of the country, this zone is the most extensive. The typical vegetation is an even cover of grass 3–4 ft. high with trees 10–50 ft. high widely scattered. The most frequent grass dominant is *Themeda triandra* Forsk. (Red Oat grass), and the uniformity with which this species tends to dominate the herbage is a striking feature of the vegetational type. The most characteristic trees are flat-topped *Acacia* species, although many other types may occur, and the acacias themselves are frequently much reduced in size. The annual rainfall of this vegetation zone varies roughly from 20 to 30 in.; it is erratic, and droughts are a feature of the climate.

The experiment here described was carried out at Ngong, in an area at the moister fringe of this vegetation, which may not be completely representative of the region as a whole, but certain aspects of the results are evidently of general application. The original object was to compare the effects of the following treatments upon an area of grassland selected for uniformity of herbage: (*a*) burning alone, (*b*) burning and light grazing, (*c*) light grazing, (*d*) medium grazing, (*e*) heavy grazing, and (*f*) complete protection from both burning and grazing. These treatments were complicated by unforeseen factors to be described later, and conclusions had eventually to be drawn from somewhat modified treatments.

The experiment was started in 1931 after the whole area had been subjected to light grazing and periodical firing. Under occupation by the Masai tribe until 1927, the fires were probably annual. At this date the area was taken over by the Veterinary Department for the breeding of Zebu cattle, and efforts were made to prevent grass fires, but not with complete success.

Vegetation on experimental area.—At the end of 1930 a preparatory

botanical survey was made. *Themeda triandra* was strongly dominant over the whole area, except on an old cart-track passing through the north-east corner of Plot E (Fig. 1) and near to the north-east corner of Plot A. Here *Cyperaceae* spp. and *Digitaria abyssinica* together with other species were more important. At the end of the experiment the cart-track could not be detected. In addition to the dominant *Themeda*, the following species were, in general, found either frequently or occasionally: *Becium ovatum*, *Sporobolus indicus*, *Polycline psylloides*, *Eragrostis paniciformis*, *E. keniensis*, *Cyperaceae* spp., *Panicum poaeoides*, *Setaria trinervia*, *Digitaria abyssinica*, *Commelina* sp., *Setaria* sp. aff., *S. setulosa*, *Achyropsis fruticulosa*. Two *Cyperaceae* species (chiefly *C. rotundus*) were involved, and the proportion of these appeared to be greater in Plots A, B, and E than in the other two.

Treatments.—The plots, each of ½ acre, were enclosed by wire fencing and arranged as shown in Fig. 1.

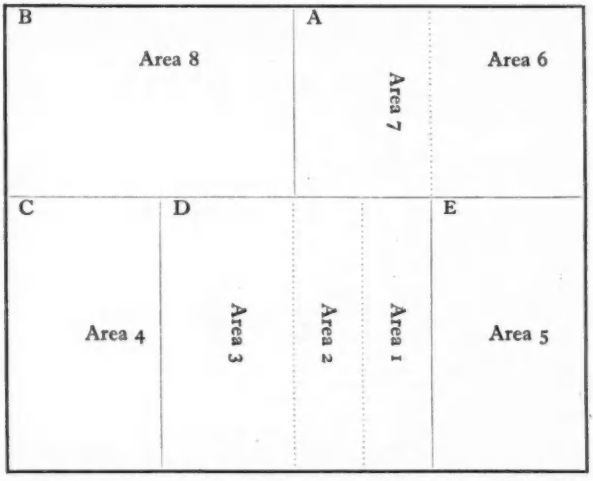


FIG. 1. Arrangement of plots showing approximate areas affected by fire.

The first burning treatment was carried out on February 17, 1931, but it was subsequently found that the animals refused to clear the dry herbage which had accumulated on the other plots and this was, therefore, cleared by cutting with scythes.

The grazing treatments were restarted on September 1, 1931, and continued until the end of 1935. There were breaks in these treatments, owing to occasional drought and locust attacks. In general, the plan followed was to continue the grazing until the heavily grazed Plot E had somewhat passed the point at which no appreciable amount of herbage was available to the animals, then to discontinue until growth had again taken place.

The intention was to imitate the native practice of light grazing and

annual burning on Plot C. It appears that the Masai use fire only when grazing has been insufficient to prevent the accumulation of old growth, and this entails a single annual burn about March over the moister part of the area occupied by the tribe. In the experiment the locust attacks and drought made it impossible to carry out a burn every year. These factors operate under native conditions, but it is believed that, in addition, the intensity of grazing employed was heavier than is usual under native pastoral conditions. Three burns were made on Plot C: in February 1931, March 1933, and September 1935. On the half of Plot D, which was subjected to grass fires without grazing, a fourth burn was found possible in February 1932. It should be noted that, over a large part of the vegetation-zone there are two distinct periods when growth is dormant: one in February and March and the other in September and October, before the long and the short rains respectively. Grass-burning is practised by the natives at both these times, although more frequently during the former period.

After the plot-treatments ceased at the end of 1935 the area was protected from both grazing and fire. By December 1936 growth had produced a considerable levelling effect in the appearance of the grazed plots and the untouched control, as opposed to the plots which had received burning treatment. At this date and subsequently it was evident that where fire had been used *Themeda triandra* constituted a very high proportion of the herbage, whereas there was only very little of it in the unburnt plots. During 1938 observations indicated that the proportions of *Setaria* spp. and *Digitaria abyssinica* were distinctly greater in all the unburnt plots than in those which had been subjected to periodical fire.

In March 1939 a fire swept into the Veterinary Farm from the surrounding Masai country and, as the fire-break around the plots was inadequate, it entered a portion of the experimental area. Fortunately, the plots which had already received burning treatment in the past were mainly affected, and it was still possible to derive further information from the experiment. It is important to note that this accidental fire was much more severe than the more frequent burns which had hitherto been practised, owing to the accumulation of herbage which had taken place during the three years of protection since the treatments were stopped to the end of 1935.

Taking into account the areas invaded by this fire, it became necessary to subdivide the experimental area into 8 plots instead of 6 (including the burnt and unburnt halves of Plot D) as at the outset. These were as follows:

(1) Part of Plot D. Complete protection from both grazing and fire for 10 years (780 sq. yds.).
(2) Part of Plot D. Complete protection for 8 years, severe fire, and further protection for 2 years (420 sq. yds.).
(3) Part of Plot D. Periodically burnt for 5 years, but not grazed, protected for 3 years, severe fire, and further protection for 2 years (1,250 sq. yds.).
(4) Plot C. Periodically burnt for 5 years plus light grazing, protected for 3 years, severe fire, and further protection for 2 years ($\frac{1}{2}$ acre).

(5) Plot E. Overgrazed for 5 years and then completely protected for 5 years (½ acre).
(6) Part of Plot A. Same light-grazing treatment as (4) for 5 years, but no fire, and then protected for 5 years (1,600 sq. yds.).
(7) Part of Plot A. Same history as (6) with the addition of a severe fire after 3 years' protection following the grazing treatment (800 sq. yds.).
(8) Plot B. Medium grazing for 5 years, complete protection for 3 years, severe fire, and further protection for 2 years (½ acre).

Light grazing: 2 oxen for 5 days and then resting for 70 days, i.e. 98 (12 hour) ox-days per acre per annum.

Medium grazing: 2 oxen for 10 days and then resting for 30 days, i.e. 364 ox-days per acre per annum.

Overgrazing: 2 oxen for 10 days and then resting for 10 days, i.e. 728 ox-days per acre per annum.

The animals remained on the plots during the days only. It is the common practice in Kenya to remove animals to a night-paddock, and in this particular area the presence of lion at intervals would have made grazing at night impracticable.

Results

In March 1941 the following notes were made on the appearance of the plots in general:

The main differences were to be seen (*a*) between the areas (3) and (4), which had received the original burning treatment, and the remainder of the experimental area; *Themeda triandra* was markedly dominant in (3) and (4) but not elsewhere; and (*b*) between the portion of Plot D which had been burnt after 8 years' protection (2), and the remaining unburnt portion of this area (1). This striking difference in appearance was due to the presence of a practically pure stand of *Digitaria abyssinica* in the area which had been subjected to a severe fire after long protection. There was no marked superficial difference between the area of complete protection (1) and the light-grazing area (6), whilst areas (7) and (8), which had received one severe burn after the grazing treatments, although they appeared to contain a high proportion of *D. abyssinica*, were not in striking contrast with the remaining grazed areas where the original burning treatment had not been applied.

In the areas of the burning treatment (3) and (4), *Themeda triandra* was strongly dominant and at the flowering stage. The shrubby Labiate, *Becium ovatum*, was frequent, *Cyperaceae* spp. frequent, the shrub *Achyropsis fruticulosa* occasional, and *Digitaria abyssinica* occasional in parts. The ground-cover appeared distinctly less complete than in the rest of the experimental area. Remains of Themeda plants killed by the severe fire which had occurred after 3 years' protection were to be seen everywhere. These two areas of burning treatment had been profoundly affected by this severe fire. Before the fire and at the end of the 5 years' periodical burning there was a normal stand of Themeda plants. Following the fire, which swept through the accumulated growth, it was estimated that approximately half the Themeda plants were killed. Some

recovery had taken place during the subsequent 2 years' protection, but the effect was still clearly visible; there was a striking increase of *Becium ovatum*, which later was again partially replaced by Themeda.

In areas (1), (5), and (6), which had escaped the severe fire of March 1939, a mat of herbage was present with a high proportion of dead matter. *Digitaria abyssinica* and *Becium ovatum* were co-dominant in (1) and (5), but the latter was less prominent in (6). The shrub *Achyropsis fruticulosa* was frequent in (1) and (6) and only occasional in (5), probably as the result of the previous heavy grazing treatment of this area. *Setaria* spp. were occasional to frequent in all three areas, and *Themeda triandra* varied from virtual absence in (5) to occasional plants in (6).

Areas (2), (7), and (8), where the severe fire had encountered an accumulation of herbage, were dominated by *Digitaria abyssinica*. *Themeda triandra* was occasional in (2) and (7) and frequent in (8). *Becium ovatum* was occasional in (7) and (8) but unimportant in (2). *Achyropsis fruticulosa* was occasional to frequent in all three areas, whilst *Setaria* spp. were fairly plentiful in (7) and (8) but practically absent from (2). The dominance of *D. abyssinica* was most marked in area (2), where the fire had entered the greatest accumulation of herbage after 8 years of complete protection. Here the appearance was that of a practically pure stand of the grass. In all three areas dominated by *D. abyssinica* the cover of herbage was distinctly more dense than in those areas dominated by *T. triandra*.

The eight areas of the experiment thus fell into three groups: (*a*) those which had received the original burning treatment and were now strongly dominated by *T. triandra*; (*b*) those which had been protected from fire for 10 years, now either co-dominated by *D. abyssinica* and *B. ovatum* or dominated by the former; and (*c*) those which had been subjected to one severe burn after 8 years' protection from fire and a period of protection from grazing which had permitted an accumulation of growth, now strongly dominated by *D. abyssinica*. The main factor which influenced the composition of the herbage was fire, the effect of the grazing treatments was subsidiary.

The records were made in the form of measurements of (*a*) basal cover [3], (*b*) canopy, and (*c*) percentage productivity. An 18-inch quadrat, divided by cross wires to facilitate reading, was used, and the quadrat was thrown at random over each of the 8 areas. Ten quadrat readings each for (*a*) and (*b*) were made in the smaller areas and 20 in the larger areas. The basal-cover records were made on cleared quadrats which had been cut for 'percentage-productivity' samples. It was not feasible to base the final records on the original meter quadrats, as the experiment had been subdivided into a greater number of areas than they were intended to represent. Further, although the five charts made give a fairly reliable picture of the experimental area as a whole at the outset, single-quadrat charts would have been inadequate to represent the various areas of dissimilar treatments. Records of basal-cover and canopy records in conjunction were deemed necessary, because frequently a plant which forms an important part of the mass of vegetation contributes to a small or even insignificant extent to the basal cover, e.g.

Becium ovatum and *Digitaria abyssinica*, while the conspicuous bases of *Themeda triandra* are more in keeping with the proportion of this grass in the canopy.

To obtain the figures for percentage productivity, 18-inch quadrat cuts were made at random, 30 quadrats in areas (4), (5), and (8), 20 in area (6), and 10 in each of the smaller areas. The cut material from each area was thoroughly mixed and a $2\frac{1}{2}$-lb. green sample properly drawn from the mass. The samples were then air-dried in butter muslin bags, and separated into the main constituents on 100-gm. quantities drawn from the samples. Analyses of the whole sample, made in four cases as a check, fully supported the results.

TABLE 1. *Composition of the Herbage at End of Experiment, March 1941: Ground-cover and Percentage-productivity Records for the Eight Areas*

(*a*) Basal cover and (*b*) canopy, both as percentages; (*c*) percentage productivity

		Themeda triandra	*Digitaria abyssinica*	*Becium ovatum*	*Commelina* sp.	Cyperaceae spp.	*Other spp.*	*Burn*	*Bare ground*	*Percentage loss on air-drying*
Area (1)	(*a*)	..	10·0	5·5	2·0	3·5	3·0	..	76·0	40·0
	(*b*)	0·5	35·5	40·5	trace	trace	1·0	..	22·5	
	(*c*)	0·8	26·8	18·8	..	..	6·5	47·0	..	
Area (2)	(*a*)	2·5	19·0	0·5	trace	0·5	1·0	..	76·5	37·5
	(*b*)	3·0	69·5	1·0	trace	0·5	trace	..	26·0	
	(*c*)	0·5	75·1	0·2	..	..	3·8	20·3	..	
Area (3) (fire treatment)	(*a*)	19·5	0·5	3·0	trace	2·5	0·5	..	74·0	50·3
	(*b*)	27·0	6·0	25·5	0·5	1·5	trace	..	39·5	
	(*c*)	47·5	5·3	21·3	..	..	9·3	16·6	..	
Area (4) (fire treatment)	(*a*)	18·0	1·3	3·8	0·8	2·3	..	..	73·8	50·0
	(*b*)	24·3	2·8	27·8	0·5	1·3	0·3	..	43·0	
	(*c*)	50·2	4·4	25·6	..	..	4·2	15·5	..	
Area (5)	(*a*)	..	10·0	0·5	0·3	3·5	0·3	..	85·4	42·5
	(*b*)	trace	35·3	23·8	0·5	2·0	0·3	..	38·1	
	(*c*)	0·9	31·8	28·0	..	..	9·3	30·0	..	
Area (6)	(*a*)	1·0	10·0	trace	0·5	6·0	trace	..	82·5	35·0
	(*b*)	..	43·5	5·0	1·0	3·5	2·0	..	45·0	
	(*c*)	1·0	45·8	1·8	..	..	15·4	36·0	..	
Area (7)	(*a*)	8·0	9·0	trace	trace	1·5	1·5	..	80·0	38·7
	(*b*)	6·5	55·5	5·0	trace	1·5	1·0	..	30·5	
	(*c*)	10·5	41·9	5·9	..	..	8·6	31·1	..	
Area (8)	(*a*)	6·5	12·5	0·3	0·3	1·8	trace	..	78·6	40·0
	(*b*)	14·8	41·0	11·0	0·3	1·5	0·3	..	31·1	
	(*c*)	19·1	34·5	9·4	..	..	6·1	30·9	..	

'Burn' = old, dead material. It will be noted that there is agreement between the estimations of the cover provided by the top canopy of the herbage and the percentage-productivity determinations, in regard to the relative importance of the species.

Examination of Soils under the Different Treatments

No investigation of the soil parallel with the study of the vegetation in this experiment was found possible, but the Soil Chemist of the Department of Agriculture analysed composite soil samples taken from each of the 8 plots and sub-plots which had been subjected to different treatments. The composite samples were made up from 10 randomized

samples taken to a depth of approximately 3 in. Certain analyses suggest that the soil conditions were uniform over the area, but no valid conclusions concerning the effects of treatments on the soil are possible unless the changes observed over the 10-year period are significantly large. In fact, the changes recorded were slight. Table 2 gives the results of the

TABLE 2. *Analytical Results on Eight Soil Samples*

Sub-plot	*Treatment*	*Hygroscopic moisture*	*Loss on ignition*	*Sticky point*	*Base-exchange capacity M.E./100 gm.*	*Mean placing*
1	Complete protection from grazing and fire for 10 yrs. . .	8·11 (1)	11·68 (1)	37·3 (1)	11·4 (1)	(1)
2	Ditto for 8 yrs., severe fire, and protection for 2 yrs. . .	6·57 (6)	11·41 (3)	35·1 (6)	10·8 (4)	(5)
3	Periodical fire for 5 yrs.; protection for 3 yrs.; severe fire and protection for 2 yrs. . .	6·80 (5)	10·63 (5)	35·5 (4)	10·4 (6)	(5)
4	Periodical fire with light grazing for 5 yrs.; protection for 3 yrs.; severe fire and protection for 2 yrs.. .	6·51 (6)	9·38 (8)	33·4 (7)	10·2 (8)	(7)
5	Overgrazing for 5 yrs. and complete protection for 5 yrs.. .	7·80 (2)	11·61 (1)	37·5 (1)	11·1 (2)	(1–2)
6	Light grazing for 5 yrs. and complete protection for 5 yrs.. .	7·48 (3)	11·11 (4)	37·4 (1)	11·0 (2)	(2–3)
7	Light grazing for 5 yrs.; protection for 3 yrs.; severe fire and complete protection for 2 years	7·31 (3)	10·74 (5)	35·7 (4)	10·7 (4)	(4)
8	Medium grazing for 5 years; protection for 3 yrs.; severe fire, and complete protection for 2 yrs. . .	6·34 (8)	9·82 (7)	32·9 (8)	10·4 (6)	(7)

various determinations made. As the differences for individual soil samples are relatively small and the four values determined tend to express a common, though not a single property, these values have been considered together as a means of tracing soil changes resulting from different cover-treatments. The relative magnitude of the values in decreasing order is noted following the absolute values found by analysis,

and the mean placing of these values is given in the last column. This gives a general picture of the placing of the 8 representative soils which can now be compared with treatments given, bearing in mind the distribution of the plots in the area.

The table shows that there is a fair agreement in the relative placing of the four values for each separate sample of soil, and that there is a good range and spacing of differences between the maximum and minimum values. The maximum difference amounts to about 25 per cent. for hygroscopic moisture and loss on ignition, and about half this amount for the sticky point and base-exchange capacity. The soil from sub-plot 1, representing complete protection with no fire for 10 years, has the maximum values, followed by that from sub-plots 5 and 6, which have had protection for the last 5 years and have not been subjected to any grass fires. Then come soils from sub-plots 7, 2, and 3, all of which had been subjected to one severe fire, whereas the treatment of sub-plot 3 also included periodical burning. Soils from sub-plots 4 and 8 are about similar and have the lowest values for the four measurements made.

As periodical mild grass fires, coupled with occasional severe fire, have probably been normal to the district, and as fire has been a contributory factor in the development of the natural soil, the major new treatment which this land has received has been protection from fire. In fact, such protection for 10 years appears to have brought about certain soil differences, whereas additional mild periodical grass fires do not appear to have added to the effects caused by the common severe grass fire. It is noted that the soil samples taken from the three sub-plots which had been protected against any grass fire for 10 years now show higher values for the empirical soil constants that express a measure of the amount of soil organic matter plus soil colloids. The protected soils are also the darkest.

Discussion

The main result of the investigation is that *Themeda triandra* has remained dominant only where periodical burning was practised for the first 5 years (areas (3) and (4)), and that where it has been suppressed *Digitaria abyssinica* has largely replaced it. For area (2), where fire invaded vegetation that had been completely protected from both burning and grazing for 8 years, the figures support the field observation that the change was accelerated by the burn. It appears that the latter species, which has a deep underground system of rhizomes, already increased as the result of protection from fire was practically the only type capable of surviving the very severe burn. The behaviour of the shrubby Labiate, *Becium ovatum*, which is the only other important species concerned, is somewhat erratic, and although it seems to have received a distinct setback as the result of the severe fire in area (2), its position is doubtful. The Themeda-dominant areas ((3) and (4)) were also affected by a fire of less, although more than usual, severity, in herbage which had accumulated for 3 years. This fire, in addition to destroying a considerable proportion of Themeda plants, resulted in a very marked increase of *B. ovatum* in the season immediately following the burn. In the two

years of protection following the burn, before the records were made, the Themeda recovered at the expense of *B. ovatum*.

Regarding the effects of the grazing treatments, it appears that overgrazing on area (5) has been at least as effective as complete protection (area (1)), in suppressing *T. triandra* and causing its replacement by *D. abyssinica*; and that light and medium grazing (areas (6), (7), and (8)) have been somewhat less effective. The higher proportion of Themeda present in area (8), as compared with the other areas which were not originally 'burnt', suggests that a medium intensity of grazing might slow down the disappearance of this grass, and that under such conditions less frequent firing may be necessary than where light grazing is practised. Areas (7) and (8) suggest that the one severe burn to which they were subjected has already begun to encourage a return of *T. triandra*. In the two areas of the previous burning treatment ((3) and (4)) light, intermittent grazing in imitation of the native practice was carried out on (4) only. These two areas are closely similar in composition, and the light grazing appears to have had little or no effect. Thus fire is the potent factor which has influenced the persistence of *Themeda triandra* as a dominant, and this effect overshadows to a great degree any results obtained from grazing. Where burning treatment has been withheld, the change from *T. triandra* to *D. abyssinica* herbage has progressed, whether grazing has been applied or not.

The conclusion that the maintenance of Red Oat grass is dependent upon periodical grass-burning is well supported by the present condition of the area surrounding the plots and of certain other parts of the Veterinary Farm at Ngong. At the outset in 1931 the surrounding area was strongly dominated by this grass. Intermittent grazing had been practised and no fire had entered the area during the period of the experiment, with the exception of the one which occurred in 1939. Red Oat grass now exists in small proportion only, and *D. abyssinica* appears to have replaced it to a large extent, whilst *Cyperus rotundus* is plentiful. In a field at some distance from the experimental area there has been no fire for at least 13 years; it was used for hay production and grazing, and good yields of hay composed largely of Red Oat grass were obtained some years ago. The crop is now stated to be insufficient for hay-making. Examination of the area shows that Red Oat grass has become very scarce, *D. abyssinica* is abundant, *Setaria* sp. is frequent, and non-graminaceous weeds are also common. It is clear that in the absence of periodical fire in both these cases a change in the herbage in the direction indicated by the experiment has taken place. Both Staples [4] and Cook [5], working in South Africa, have shown the influence of fire in maintaining *Themeda triandra*.

To explain why *Themeda triandra* is less affected by fire at frequent intervals than other species, it must be assumed that this grass is specially adapted to resist fire. Observations have shown that Themeda possesses an adaptability enabling it to propagate itself under conditions of periodical fire. The seed is equipped with a mechanism which results in its burial well below ground surface. The strong, twisted awn is rapidly affected by changes of moisture, and rotates in such a way as to cause the

seed to move along the ground-surface until an obstruction is encountered, when it begins to enter the soil. The point of the seed, which is hard and extremely sharp, is fringed with a ring of stiff bristles lying back and serving to anchor the seed in its forward and downward movements. To confirm these observations, some Themeda seeds were placed on loose soil in the laboratory and subjected daily to a fine spray of water. Immediately the awns were seen to twist slowly, giving the seed a twisting motion and causing it to move over the soil surface. Occasionally an awn assumed a looped position and then suddenly became released, causing the seed to jump forward. Eventually, 20 out of a total of 22 seeds worked themselves below the surface of the soil up to a depth of 1 in. These seeds would be adequately protected from the effects of grass fire according to results obtained recently in South Africa [5], where it was found that the maximum depth to which the heat penetrates is 0·2 in. Confirmation was obtained in the field when a light shower of rain occurred during hay-cutting operations. A very high proportion of the seed which had fallen to the ground had disappeared below the surface, leaving only the tips of the awns exposed. Under natural conditions the seeds frequently enter cracks, which are plentiful in the dry season, and the dew at night alternating with the hot sun by day is probably sufficient to produce movement of the awns. Often the obstruction which causes the seed to turn into the ground is the base of another grass, and this fact appears to explain why Themeda plants are frequently found growing through tufts of other grass species and eventually suppressing these species in an area which has been subjected to fire.

Over past centuries the native tribes occupying these vast grasslands have practised grass-burning, but the factors leading to the present type of vegetation are believed to be deeper and more remote than the comparatively recent activities of man. The vegetation most probably developed from its earliest stages under the influence of periodical fire caused by volcanic activity. Most of the numerous volcanoes of Kenya show unmistakable signs of recent activity, and there are considerable areas of lava, which vegetation is only beginning to colonize, whilst some volcanoes in neighbouring territories are still active.

Since to-day most grass fires are caused by man, the question arises whether their prevention is desirable. The experiment here described was carried out in a relatively moist region, so that the results may not be valid for other regions; but they do suggest that the effect of preventing grass fires would be profound anywhere within a wide climatic belt of fire-tolerant vegetation. *D. abyssinica* is very widespread and seems to dominate a transitional phase between grassland vegetation and woody vegetation; it is a very common indicator of soil impoverishment due to over-cultivation and over-grazing. Though it has deep underground stems and usually produces a light cover of herbage, the leafage tends to wither in the dry season. Hence the replacement by it of Red Oat grass would appear to be a bad exchange.

As the use of fire in the management of grassland is not confined to the Acacia–Tall Grass vegetation, a study of the practice in each of the other

main types of vegetation is necessary before plans can be made for these regions. Observations in the moist highland areas of Kenya indicate that grass-burning is a factor determining the balance between two distinct types of grassland. In this climatic zone the ideal line of development is the intensive management of Kikuyu grass (*Pennisetum clandestinum*) and clover pastures, but sparse occupation has resulted in the light management of extensive areas. Under such conditions the grassland tends to become dominated by the extremely coarse *Pennisetum Schimperi* (Wire grass), and by means of grass-burning this species can be suppressed in favour of *Themeda triandra*. Where the type merges into the Acacia–Tall Grass vegetation there is a considerable belt of country in which a similar problem arises. Here the rainfall is too low for intensive management, and *P. Schimperi* again tends to replace *T. triandra*. It appears that in this transitional belt periodical fire is essential to maintain a utilizable pasture type.

Although the data obtained on the effect of 'burning' on the soil are indefinite, they suggest that the physical properties and organic-matter content might be improved if the land could be completely protected from fire over a period of years. If the soils of the vegetational region concerned have, in fact, developed in equilibrium with fire, then no degradation should result from its continued use, provided that periodical over-grazing and other disturbing factors are controlled. No sign of soil erosion was observed in the burnt areas of the experiment. Little experimental evidence is available from other countries, but the conclusions reached suggest that too much weight has been given to possible soil deterioration, and that the good effects of the practice in maintaining economically valuable vegetation outweigh the advantages to be derived from withholding fire. This view agrees with the findings of Cook [5] in South Africa, and those of Vincent [7], based on 30 years' experience in South America. Wahlenberg, Greene, and Reed [8], in a 10 years' study of the effects of fire and grazing in the long-leaf pine region of McNeill, Mississippi, U.S.A., found that both fire and grazing adversely affected the physical properties of the soil, though fire improved the chemical properties. These workers concluded that soil organic matter is maintained at a higher level in grasslands that are frequently burnt over—a finding which is in direct opposition to the common view.

Fire is an essential factor in the environment of the most extensive grasslands of East Africa, and for pasture it must be accepted as a necessity. This does not, however, imply that the present practice of uncontrolled grass-burning is to be commended. It is evidently desirable to avoid further destruction of forest, and it is also desirable to protect catchment areas and steep slopes which, under uncontrolled grazing and burning, are particularly vulnerable to soil erosion. The protection of these areas by the exclusion of fire will, in most cases, involve the cessation of grazing and the return of the area to bush or forest.

In a region the greater part of which is occupied by roving native pastoralists, fire control is extremely difficult. The provision and maintenance of fire-breaks is a huge undertaking, and various suggestions, intended to limit the use of fire by legally restricting the times when

grass-burning would be permitted, have been put forward. The chief of these suggestions are, (*a*) that burning should be permitted only at intervals of several years, and (*b*) that a 'close season' for burning should be declared at the height of the dry season when, it is argued, there is most danger of fires spreading rapidly. In regard to (*a*), the work already discussed shows that, unless grazing is sufficient to prevent the accumulation of old growth, the effect of infrequent fires would be disastrous. In native areas, and to a lesser extent also in areas of European settlement, the intensity of stocking is determined by the carrying capacity of the grassland in the dry season, and the animals available are inadequate to deal with the rapid growth resulting from the wet season. Suggestion (*b*) implies burning, either before the grass seed is ripe, or in the early part of the wet season when growth would have started and seedlings would be developing. In the former case it will be apparent that eventually the dominant Red Oat grass would be suppressed through destruction of the seed crop. In the latter case no direct evidence of the effects to be expected in East Africa is yet available, but it may be assumed that, if such a departure from present practice could be attained, it would result in a marked change in the vegetation. Both Staples and Cook (already quoted) in South Africa found that burning when growth had started caused suppression of *Themeda triandra* (Red Oat grass), and Gill [9] states that deterioration is certain to result. Despite the magnitude of the undertaking, it appears that the use of fire-breaks provides the only feasible means of control of grass fires.

The practical conclusions to be drawn from the results of this experiment may be summarized as follows:

(1) In order to maintain suitable pasturage, it is necessary to employ fire periodically, in the dormant season of the year, after the bulk of the grass seed has ripened. If grazing is sufficient to prevent the accumulation of old growth, grass-burning need not be annual and would probably suffice if used every second or third year.

(2) Where attempts are made to protect the vegetation from both fire and grazing for any reason, the method of protection must be completely reliable. If fire invades an area so protected, after a number of years, it results in very marked undesirable changes in the vegetation.

As development proceeds, the aim should be to use fire as a controlled instrument of grassland management. This aim would involve a much greater measure of control of grazing than is at present practised. The fact that under certain circumstances recovery of the herbage after burning is extremely slow has been cited as an argument against the use of fire, but this disadvantage may be largely counteracted by observing certain precautions. Either firing of accumulated growth (by destruction of a high proportion of the plants), or firing when active growth has started, may lead to slow recovery. The burnt area should not be subjected to heavy grazing in the early stages of growth and establishment of the seedlings. Where fencing is not provided and when a limited area only has been fired, this almost invariably happens, because young grass is very attractive to animals. Where large tracts of country have been

burnt, as often happens in native areas, there is not so great a tendency for cattle and game to concentrate, although rotational control of grazing would be a desirable advance in view of this tendency and other considerations.

Acknowledgements.—Thanks are due to Mr. J. Anderson, in charge of the Veterinary Farm at Ngong, who supervised the experiment in my long periods of absence, and to Mr. Gethin-Jones, who provided the notes on soil given in the text.

REFERENCES

1. D. C. Edwards, A Vegetation Map of Kenya. J. Ecology, 1940, **38**, 377–85.
2. J. E. Weaver and F. E. Clements, Plant Ecology, McGraw-Hill Book Co., 1929, pp. 10–18.
3. J. T. Sarvis, Composition and Density of the Native Vegetation in the Vicinity of the Northern Great Plains Field Station. J. Agric. Research, 1920, **19**, 63–72.
4. R. R. Staples, Studies in Veld Management. Dept. Agric., Union of South Africa, 1930, Science Bulletin No. 91.
5. L. Cook, A Contribution to our Information on Grass-burning. S. Afric. J. Science, 1939, **36**, 270–82.
6. D. C. Edwards, The Reaction of Kikuyu Grass (*Pennisetum clandestinum*) Herbage to Management. Empire J. Expt. Agric., 1940, **8**, 101–10.
7. C. Vincent, The Burning of Grassland. Rev. Industr. Anim. (from Herbage Abstracts, 1935, **6**, 50).
8. W. G. Wahlenberg, S. W. Greene, and H. R. Reed, Effects of Fire and Cattle Grazing on Longleaf Pine Lands as Studied at McNeill, Mississippi. U.S. Dept. Agric., 1939, Tech. Bull. No. 683.
9. G. A. Gill, Veld-burning Experiments. Farming in S. Africa, 1936, **2**, 134.

(*Received February 10, 1942*)

THE DURATION AND EXTENT OF PEDIGREE BREEDING IN HERDS OF LARGE WHITE PIGS AS A FACTOR IN BREED IMPROVEMENT

H. P. DONALD AND C. AUERBACH

(*Institute of Animal Genetics, University of Edinburgh*)

THE principle of continuous adaptation of farm live stock to environment and destiny will have to be taken into account by any comprehensive plan for improving the efficiency and stability of post-war agriculture. Just as the change from open-field farming to enclosures permitted and required improvements in live stock, the absorption of recent technical advances in husbandry into practice will require suitable stock for their complete realization. It seems desirable to inquire, therefore, whether the existing system of obtaining improved stock through the initiative and enterprise of individual breeders will be adequate to the demands made upon it, and if not, how it can be made more effective. The use of show standards as a guide to live-stock improvement tends to obscure the fact that improvement may also include on occasion the reversion to a less 'improved' but economically better type, or to a change from one breed to another. At present there seems to be no system at all to secure such advantages. Any inquiry must therefore be restricted to pedigree breeding, which is the means by which superior stock of established breeds is developed and made available to breeders generally. As a contribution towards such an inquiry, a study has been made of the sources of pedigree Large White pigs with reference to two aspects which, although important, have received but little attention. The first of these is the duration of the individual breeder's effort. Constructive breeding is necessarily a long and empirical process, and the supply of improved strains must clearly be affected by the number of breeders who have been working at the task for the necessary length of time. The second aspect is the extent of each breeder's operations; this is significant, not only as a measure of his scope for designing matings and for selection, but also as a measure of his contribution of breeding stock to the population of pedigree pigs. Those who have created improved strains can influence appreciably the frequency of desirable genes in the whole population only if such strains are distributed to other breeders in sufficient numbers to prevent the complete loss of their qualities by dilution. Obviously, a breeder's work cannot be judged only by the length of his experience and by the number of breeding animals he adds to the population, but these two factors must profoundly affect his potentialities for constructive breeding.

Material.—Since it has not been feasible to determine for a sufficient number of breeders exactly how long they have been engaged in pedigree breeding, or how many pedigree animals they have bred, estimates have been made from a sample of the data recorded in the herd-books. The sample included all herds with a prefix beginning with one of the letters

B, D, G, M, P, S, W, and represented by entries in one or more of the volumes appearing for the years 1920–40. The number of sows entered was recorded for each volume and herd, and the duration or length of life of each herd was fixed as the number of years from the first to last entries inclusive. Entries of sows rather than of boars were used because sows are more numerous, are derived to a greater extent from home-bred

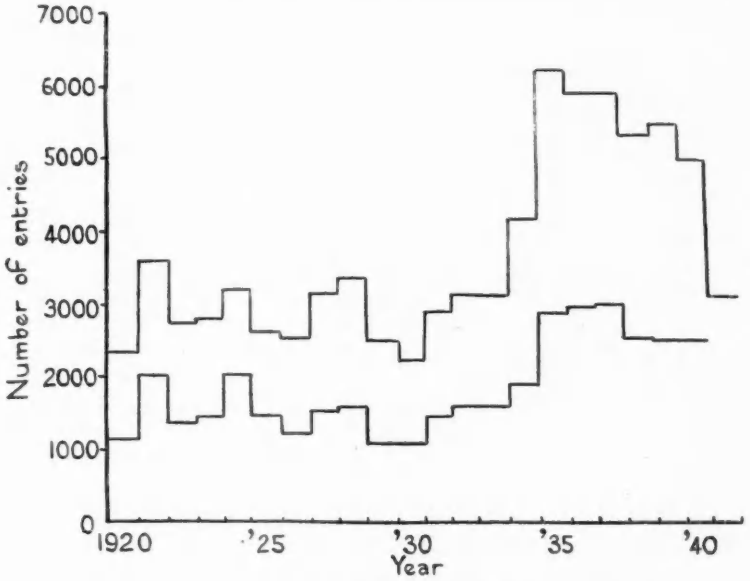


FIG. 1. Number of sows entered in the Large White herd-books. *Above*: total entries. *Below*: entries made by herds in the sample.

parents, and give less weight than boars to any herds that are less concerned with pedigree breeding than with supplying a local demand for pure-bred sires. The principal errors inherent in this method are that a small proportion of breeders began entering boars a year or more before they entered sows in the herd-books, and that in some herds pedigree breeding temporarily ceased for one or more years. These sources of error should tend to cancel each other in respect of estimates of duration for the whole sample, and are unlikely to affect the general conclusions. In order to complete the life-histories of herds appearing in vol. 36 (1920), the number of sows entered by those herds in previous years was kindly provided by the National Pig Breeders' Association. The total number of herds considered was 1,153, which was approximately half the breed total. The number of sows entered by these herds in each volume bore about the same relation to the breed total. This is shown in Fig. 1, which also shows how the numbers of pure-bred sows registered have increased and then decreased since 1933.

A Classification of Herds by Stage of History and Number of Sows Registered

In order to obtain an estimate of the rate at which new herds were appearing and others disappearing, a classification of the herds was made for each year according as they were making their first, last, intermediate, or only entries. Thus a herd making entries in four consecutive volumes would be classified as a first for one year, as an intermediate for two years, and as a last in the fourth year. Those intermediates which made no

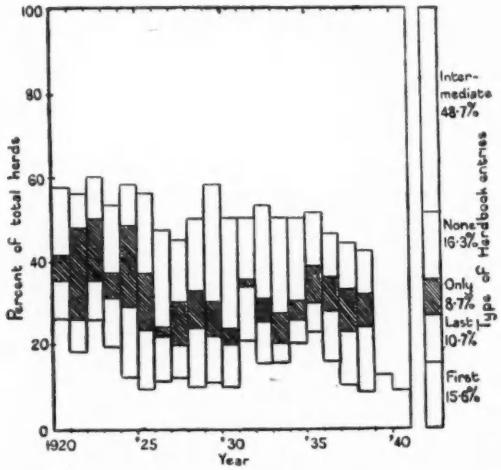


FIG. 2. Classification of herds by type of entry as shown by right-hand column, which gives average percentage values over 18 years. The classification for 1938 is doubtful and is not included in the averages.

entries were separately noted. In each year, therefore, the herds concerned have been divided into five classes. By reducing the results to a percentage basis, the proportions which these classes bore to each other and to the total can be seen from the graphical presentation of the data in Fig. 2. The column on the right shows how the figure has been constructed, and gives the average values for the years 1920–37. Two years without entries not being unusual, the distinction between last and intermediate entries for 1938 is doubtful, since there were only two subsequent years by which to test the classification, and the data have therefore been excluded from the average. For 1939 and 1940, only first entries could be recognized with certainty.

Year-to-year variation in the size of the classes has been considerable and is no doubt largely influenced by economic factors as, for instance, in the periods 1920–3 and 1931–6 when the number of new herds was relatively high. On the whole, however, there does not appear to be any very striking relation between the classes. The chief feature of the data is that about half the herds have been either just beginning or ending

their existence, or making no entries. Of these, a rather large but variable number made entries for only one year.

Subdividing the herd classes according to the number of sows entered provided the data from which Fig. 3 has been constructed. With some exceptions, too few to show graphically, all herds making their first, last, or only entries in any year entered less than 21 sows each in that year. Intermediate entries have been placed into size groups with the following limits: 1–20, 21–50, 51–100, and 101 or more entries. Summing the actual numbers of entries in these groups and classes, averaging for the 18 years, and reducing to a percentage basis, gives the comparison in Fig. 3 between the class of herd and its contribution to the total entries made.

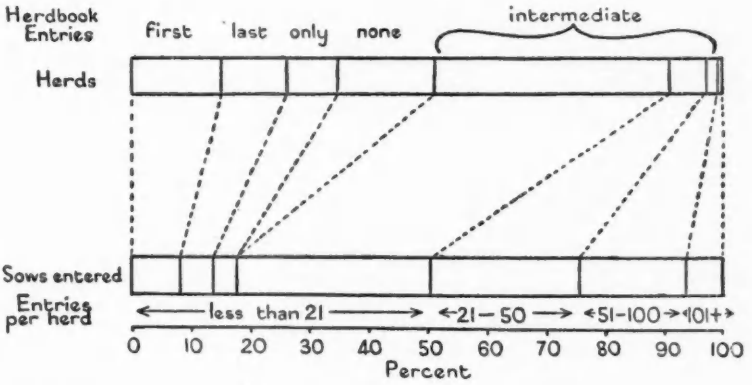


FIG. 3. The average annual contribution from 1920 to 1937 by herds of various classes to herd-book entries of sows.

On the average, about 15·6 per cent. of the herds entering sows in any year did so for the first time. Another 8·7 per cent. made their only registrations, and 16·3 per cent., although still in being, registered none. Herds making their last entries and (as will be shown later) composed mainly of those which existed only for a short time, amounted to another 10·7 per cent. in each year. These classes together account for about 50 per cent. of the total herds, but only for about 18 per cent. of the sows. Whatever their value as a means for extending the market for and use of superior pigs bred by others, these herds can be of little importance for constructive breeding.

Herds at some intermediate stage of their history, but registering fewer than 21 sows, made up the largest class (40 per cent.) and with an average of 6·7 sows entered, provided 32·5 per cent. of the total entries. The majority of these sows appear to have been retained for herd replacements. The remaining 9 per cent. of herds registered over 20 sows each per year, which together amounted to 50 per cent. of the total sows registered. The 354 yearly records which formed the basis of this last estimate included only 17 which were classed as first, last, or only

registrations. This small proportion has not been shown separately. If it is assumed that (1) herds making their first or only entries can have accomplished little if any constructive breeding; (2) herds making their final entries have ceased constructive breeding; and (3) the class of herd averaging only 6·7 sow entries per year are mainly small one-sire herds offering little scope for matings and selection, and frequently introducing unrelated boars—these figures suggest that in at least 50 per cent. and probably 90 per cent. of pedigree herds the duration and scale of breed-

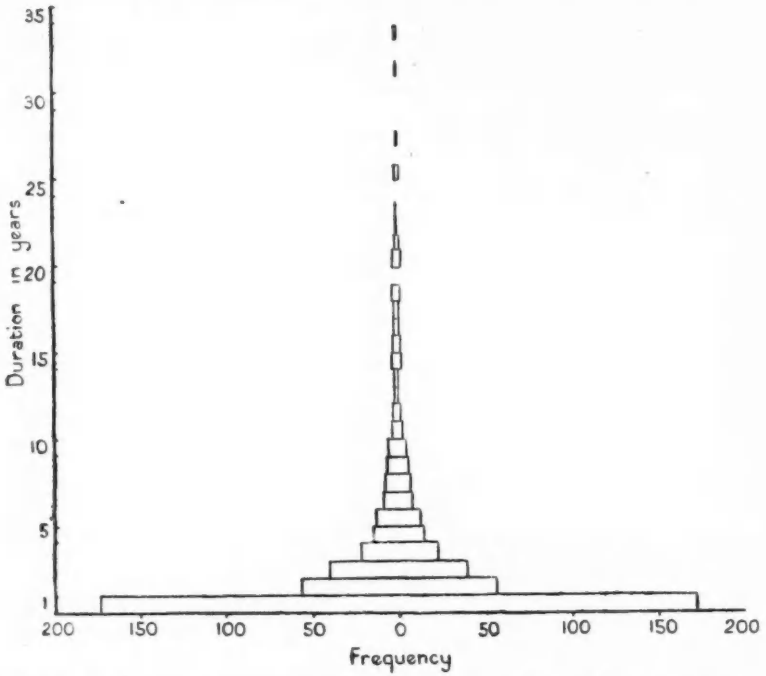


FIG. 4. Frequency distribution of duration in years achieved by 753 herds which ceased to register sows between 1920 and 1937 (for data see Table 2).

ing operations impose severe restrictions on the possibility of constructive breeding. In 9 per cent. of herds these two factors would appear to be much more favourable to an effective influence on breed improvement. Included in the 9 per cent., however, are herds which have lasted for as little as three years.

Distribution of Herds according to Duration

During the 18 years from 1920–37, 753 herds appearing in the sample ceased to register sows. Since the number of years in which they registered sows was known, an estimate of the distribution of herds by duration or length of life could be made. This distribution is shown in

Tables 1 and 2, and graphically in Fig. 4, which has been drawn so as to suggest the gradual multiplication or dilution of breeding pigs from old established herds as well as the high 'death-rate' of immature herds.

It will be noted that any herd making its initial entries has but a small prospect of continuing for more than 5 or 6 years. To build up a herd of any real permanence for the production of breeding stock, a breeder must clearly surmount economic and other difficulties which prove too severe for the majority.

The average length of life on these data is only 3·6 years, or less than two sow generations, yet some 75 per cent. of the herds achieved less than this. There has, however, been a recent tendency for herds to survive rather longer than before, so that this estimate based on the past may be smaller than the immediate pre-war value. As might be expected, there is some variation in the distribution of herd-duration when short periods of time are considered. Table 1 shows how the average duration varied from 2·8 to 4·8 years in sub-samples of herds ceasing to make entries within three periods of 6 years. The most notable differences are found in the classes which made entries for only 1 year and for 6 to 10 years, but otherwise the general trends are similar in each period. Since the proportion of herds making entries in only 1 year varied significantly between periods, the figures suggest, as would be expected, that when the total 'mortality' is high, the youngest herds are the most sensitive to the unfavourable conditions.

TABLE 1. *Herd Duration*

	Frequency in per cent.		
Duration (years)	*Vols. 36–41 1920–5*	*Vols. 42–7 1926–31*	*Vols. 48–53 1932–7*
1	54	35	44
2	15	14	16
3	12	10	10
4	7	7	5
5	3	4	5
6–10	4	21	14
11–15	3	5	3
16–20	1	3	2
21–34	1	1	1
	100	100	100
No. of herds	294	174	285
Average duration	2·8 yrs.	4·8 yrs.	3·7 yrs.

When the number of herds which survive any particular age is expressed as a percentage of the number which survived the preceding age, the sequence of values obtained shows close agreement. Over the age-range 4–15 years the number of herds which exceeded each age was consistently about 80–86 per cent. of the number which exceeded the preceding age. Over this range, therefore, the prospects that a herd would continue for any given time was of the order of $0{\cdot}8^n$, where n is the time in years. Since the percentage survival was 54·1 for herds of 1 year's

standing and 72 for those of 2 and 3 years', their prospects were somewhat poorer. Owing to the small numbers available, the percentage survival became erratic after 15 years.

Relation between Duration and Number of Herd-book Entries

A comparison of the numbers of sows entered by herds of varying duration (Table 2) shows that in the sample there was a slight increase in the average number of herd-book entries per year for each herd as the duration rose from 1 to 10 years. After 10 years the average increased suddenly from 5·8 to 9·7 and more sows per year. Regrouping the data according to the average number of sows registered per year, instead of according to duration, showed much the same relation—the average duration of herds making a moderate or low number of entries was substantially lower than that of herds making many.

It does not follow that larger herds, like larger entries, would tend to be associated with higher average duration, although that may be so.

TABLE 2. *Relation between Duration and Number of Herd-book Entries*

	Herds		*Sow entries*		
Duration (years)	*Number*	*Per cent. of total*	*Av. No. per herd per year*	*Total No. of entries*	*Per cent. of grand total*
1	340	45·2	4·3	1,459	8·3
2	115	15·3	3·9	904	5·2
3	81	10·8	4·3	1,050	6·0
4	46	6·1	5·8	1,069	6·1
5	30	4·0	5·2	787	4·5
6–10	88	11·7	5·8	3,866	22·1
11–15	27	3·6	9·7	3,343	19·1
16–20	14	1·9	9·9	2,392	13·7
21–34	12	1·6	12·5	2,609	14·9
Totals	753	100·2	..	17,479	99·9

Table 2 shows further that the lifetime contributions of registered sows made by herds of long duration (which have been adjusted in the case of herds of more than 18-years' duration by taking as their total entries only eighteen times their average annual number of entries) considerably outweigh those of the much more numerous short-lived herds. The values in the last two columns show in a purely numerical way the cumulative influence on the breed exerted by a few breeders. Their importance is brought out more clearly in Table 3, in which the herds are classified according to average number of herd-book entries of sows per year and as either of short (less than 10 years) or long (more than 10 years) duration.

It shows that only 2·3 per cent. of all herds survived more than 10 years and averaged 11 or more sow entries per year, but their contribution to the total breeding-sow population was 34·7 per cent. This implies a considerable responsibility for the breeders concerned. If they all favoured the same genes and were all skilful in selecting and breeding

for them, they should have exercised a considerable influence on the breed. The other 65·3 per cent. of the sows were bred by 736 breeders of

TABLE 3. *Relation between Duration and Number of Herd-book Entries*

Duration (years)	*Av. No. of sows entered per year*	*No. of herds*	*Per cent. of total herds*	*No. of sows entered*	*Per cent. of total sows entered*
1–10	0–5	534	70·9	3,739	21·4
	6–10	116	15·4	2,293	13·1
	11–20	39	5·2	1,895	10·8
	21–	11	1·5	1,208	6·9
11–34	0–5	25	3·3	1,119	6·4
	6–10	11	1·5	1,170	6·7
	11–20	12	1·6	2,950	16·9
	21–	5	0·7	3,105	17·8

less than 10 years' standing or with rather small pedigree herds. Of these the great majority have bred less than 4 generations of pigs and worked on a small scale. As a group also, they were so numerous as to make uniformity of ideal unlikely.

Age-distribution of Existing Herds

Although giving some idea of the degree of permanence and stability under which pedigree breeding of pigs is carried on, the statistical conception of individual herd-duration does not give an accurate account of the age-distribution of the herds from which the entries in any one year are made. To provide information on this point, herds-in-being in four particular years have been classified according to the number of years since their first entries. In Table 4 the frequency distributions on a percentage basis for the herd-book years 1925, 1935, 1939, and 1940

TABLE 4. *Percentage Distribution of Herds according to Age*

Years	*1925*	*1935*	*1939*	*1940*
	Per cent.	Per cent.	Per cent.	Per cent.
1	22·7	32·1	17·8	16·2
2	15·5	14·6	9·1	10·4
3	12·9	10·0	9·1	7·1
4	13·4	8·1	13·3	7·5
5	9·3	7·8	12·5	7·9
6–10	15·5	12·8	23·9	31·1
11–15	2·1	8·4	4·2	7·5
16–20	3·6	3·4	5·7	6·6
21–	5·2	2·8	4·5	5·8
No. of herds	194	321	264	241

have been brought together. The data for 1939 and 1940 are incomplete in respect of the herds which entered no sows, since it was not possible to distinguish those which had ceased breeding from those which happened to register no pigs. In earlier volumes about 16 per cent. of all

herds made no registration in any one year, and were distributed fairly evenly in all age-classes except the first.

The years 1925 and 1935 have been chosen as years in which there were comparatively few and many new herds respectively (see Fig. 2). The position in recent years is shown by the figures for 1939 and 1940, which concern pigs bred before the war and which include rather few new herds.

It will be noted that the proportion of herds of 1–3 years' standing is smaller than that obtained from the distribution of total durations (68·6 per cent.). This is because, in addition to the low intake of new herds, the rate of 'mortality' is higher among the short-lived herds than among the long-lived. Short-lived herds therefore contribute more to total 'deaths' than to total living herds. In spite of the differences between the four years, it seems likely that at least 80 per cent. of all herds in being at any time are not more than 10 years old. At times when pedigree breeding attracts new breeders the percentage may be higher, but if at the same times the average duration is increased there may be little change except in the total number of herds. It is noteworthy that in 1940, when the total number of herds in the sample declined, there was an increased proportion of long-established herds. These herds, however, as in other years, included many which made very few entries of sows. This is brought out in Table 5, in which the herds making registrations in 1939 and 1940 are classified according to number of entries. In this table, the entries of boars are also included, but the herds entering them are classified by the actual number entered instead of by their average to date.

TABLE 5. *Numbers of Boars and Sows entered in the 1939 and 1940 Herd-books by Herds of Long and Short Duration*

		Boars				*Sows*			
		1939		*1940*		*1939*		*1940*	
Age (years)	*No. of entries*	*Per cent. of total herds*	*Per cent. of total boars*	*Per cent. of total herds*	*Per cent. of total boars*	*Per cent. of total herds*	*Per cent. of total sows*	*Per cent. of total herds*	*Per cent. of total sows*
1–10	0–5	65·9	24·1	62·5	23·6	50·8	17·0	50·2	14·8
	6–10	9·1	12·8	8·1	10·9	19·3	19·5	17·4	12·3
	11–20	4·8	12·6	2·7	7·2	11·7	16·3	8·7	14·3
	21–	1·4	8·3	2·2	11·6	3·8	18·1	3·7	22·5
11–	0–5	8·2	4·1	16·3	8·4	4·9	2·3	6·6	4·5
	6–10	4·3	6·3	2·2	3·3	3·4	3·8	6·2	5·5
	11–20	3·8	12·1	2·7	7·7	3·4	4·9	3·7	4·0
	21–	2·4	19·7	3·3	27·3	2·7	18·0	3·3	22·1
Total herds	..	208	..	184	..	264	..	241	..
Total pigs	..	..	1,076	..	1,016	..	2,547	..	2,435

The two main sources of pedigree boars are seen to be numerous young herds breeding less than 5, and a few older herds breeding more than 20 each per year. Together these two classes of herd produce about half the

boars. As regards sows, the origin of the entries seems to be similar, except that herds making 0–5 entries are relatively fewer.

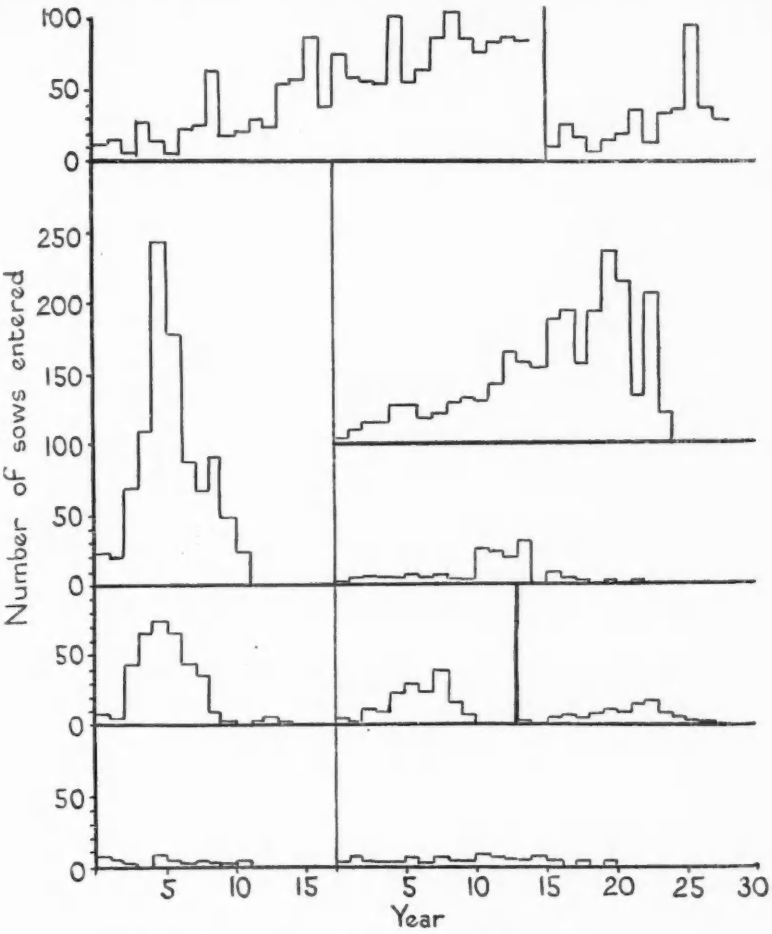


FIG. 5. Annual herd-book entries of sows made by individual herds.

Rise and Decline of Individual Herds

A pedigree herd, like an organism, has a beginning, a period of growth and development if it becomes established, and often a period of decline preceding the inevitable end. Like an organism, also, its period of growth and development is affected by circumstances and may be abruptly terminated at any stage. Its vitality, efficiency, and influence in the production of improved pigs must vary with the stage of its history.

To illustrate this point a number of diagrams have been drawn to show the yearly changes in numbers of sows entered into the herd-books by certain herds. These have been chosen to show common types of history occurring among herds which lasted at least 10 years, and to indicate the general tendency for the rise and decline to become more pronounced as the average annual production of registered sows increases above that of the lowest classes in which the rise and decline are not evident from the available data. Except for the two uppermost, the diagrams represent completed histories. Of these two, the older herd would appear to be at a critical stage from which it must either continue to expand or begin to diminish, while the younger seems to have begun its decline.

Of the remainder, some exemplify the type which expands rapidly and reaches its peak within a few years; and some the type which expands more slowly and reaches its peak after many years. It may not be without significance that all the important long-lived herds falling within the sample studied have been of the latter type. Moreover, they pass through an initial period when their influence is slight.

Herds of less than 10 years' duration, although the most numerous, are not shown, for the great majority have had neither the time nor the number of entries to exhibit the growth form of the herds with extensive histories. They give the impression of having struggled unsuccessfully for existence as pedigree herds.

Among herds which attain a considerable age there is a special class belonging to educational or hospital institutions which are probably less susceptible to the economic and human changes which affect privately owned herds. Of the 48 herds in the sample which had lasted more than 10 years up to their 1940 entries, 10 were maintained by institutions; and 21 more institutional herds were 1–10 years old. The ratio of long- to short-lived herds of this type (10:21) is about double that for all herds (48:193). Since the pedigree pigs which these institutions breed become part of the total population of pedigree pigs, the herds supplying them must be included in a survey of the sources of such pigs. The estimated average duration of pedigree herds is, however, likely to be increased above its real value for private breeders.

Discussion

To judge by the representative sample used, it seems probable that those who undertake the breeding of pedigree Large White pigs are subject to a severe degree of selection. The comparatively few survivors who build up a reputation and a large output of breeding stock bear the responsibility of forecasting and meeting the needs of those who raise commercial stock. From the point of view of the industry at large, it is therefore important to know how far the factors governing survival are compatible with the breeding policy and ideals demanded by active improvement in commercial characters. The high rate of mortality among pedigree herds makes it inevitable that the prime concern of most breeders must be profit. The skilful combination of genetic and environmental effects on conformation which marks the successful breeder often

results in a high standard of individual quality, but the further step of raising the general level of inherited performance, especially in respect of characters like milk production which are not readily judged, is likely to be difficult as long as the necessary testing is financially unattractive and the extensive intercrossing of popular families scatters any superior gene combinations that may be built up.

As Lush and Molln conclude from their study of litter size and weight [1], and as the large amount of non-genetic variation in these characters implies [2, 3], rapid progress in breeding for larger or heavier litters will apparently require much use of lifetime averages and of selection on a family basis. Most Large White herds, however, appear to introduce new blood frequently, discard sows while still young, and retain many breeding animals from comparatively untried sows [4, 5]. Since it appears also that many registered animals are produced by breeders of relatively short experience, the data now presented suggest that a rather large proportion of the pigs entered in the herd-books cannot result from constructive breeding in the genetic sense. The total number of pedigree breeders (that is, those who breed animals eligible for the herd-book) must likewise be greatly in excess of the number which at any time are actually improving breed standards. The numerous 'junior' herds are of course essential as the source of skilled breeders, and as distributing agents, under the existing methods of producing pedigree pigs; but it may be doubted whether these methods are at present as efficient as is desirable for ensuring that improvements reach the commercial pig, and for enabling breeders to cope successfully with the problem of improving several economic qualities simultaneously.

Summary

1. The duration and scope of the breeding effort made by individual breeders has been studied in a sample of 1,153 herds drawn from data on sow entries in the Large White Pig Herd-books for the years 1920–40 (Fig. 1).

2. About 51 per cent. of the herds in each year were making either their first, final, or only entries, or made no entry although still in existence. They produced only about 18 per cent. of the sows entered. Of the remaining 49 per cent. of the herds which were at some intermediate stage of their history, about 9 per cent. accounted for almost 50 per cent. of the entries (Fig. 2).

3. During the 18 years from 1920–37, 753 herds in the sample ceased making entries. The average duration of these herds was 3·6 years or less than two sow generations, but 75 per cent. of them achieved less. The distribution of their individual durations showed a rapid decline in frequency with increasing age (Fig. 3 and Tables 1 and 2).

4. The average number of entries per year per herd showed little variation among herds lasting for 10 years or less. After 10 years the average increased suddenly from 5·8 to 9·7 and more entries (Table 2).

5. In the 1939 and 1940 herd-books about 6–7 per cent. of herds in the sample had been in existence for more than 10 years and had averaged

more than 10 sow entries per year. They produced about 23–26 per cent. of the sows entered in these two volumes (Table 4).

6. Examples are given of the rise and decline of individual herds (Fig. 5).

7. It appears that a large proportion of registered pigs is produced by breeders of relatively short experience, and that real constructive breeding is limited to comparatively few herds.

REFERENCES

1. J. L. Lush and A. E. Molln, Proc. Amer. Soc. Anim. Prod., 1937, 133–7.
2. H. O. Hetzer, W. V. Lambert, and J. H. Zeller, U.S. Dept. Agric., 1940, Circ. No. 570.
3. J. H. Bywaters, Genetics, 1937, **22**, 457–68.
4. H. P. Donald, Empire J. Expt. Agric., 1940, **8**, 185–9.
5. ——, ibid., 1941, **9**, 236–47.

(*Received June 2, 1942*)

NEW VARIETIES OF SPRING WHEAT RESISTANT TO STEM RUST IN THE CANADIAN WEST, AND THEIR GENETICAL BACKGROUND

K. W. NEATBY

(*Director, Agricultural Department, The North-West Line Elevators Association, Winnipeg, Canada*)

Introduction.—The conquest of stem rust of wheat in the hard red spring-wheat area of Canada and the adjacent states is, for the time being at least, complete. The problem proved to be much less complex than it seemed as recently as about 17 years ago. In 1907 Dr. E. M. Freeman began a wheat-breeding programme at University Farm, St. Paul, Minnesota, with the definite aim of developing rust-resistant varieties of bread wheat. For about 10 years there was but little reason for encouragement. All available varieties of *Triticum vulgare* were susceptible, so that it became necessary to resort to interspecific crossing, making use of resistant varieties of *T. durum* and *T. dicoccum*.

At about the same time, or a little later, researches on the biology of *Puccinia graminis tritici* were initiated at the same institution. The discovery of the existence of numerous physiologic races of *P. graminis tritici* by E. C. Stakman and his associates [1, 2] added greatly to the apparent complexity of the problem. In breeding for resistance to stem rust, the causal organism could no longer be regarded as a single entity. Indeed, it appeared as though much crossing and re-crossing would be necessary in order to combine in one variety resistance to all known physiologic races.

In view of the extensive literature dealing with the pathological phases of the stem-rust problem, much of which emphasizes the importance of physiologic specialization in relation to breeding, it will seem remarkable to many that success has been achieved in so short a time. Few botanists are entirely ignorant of the results of researches on the biology of *P. graminis tritici* carried out in Canada and the United States. However, the equally important researches on the genetics of stem-rust resistance in wheat, which have formed an essential part of breeding projects, have attracted comparatively little attention, except among those actively engaged in breeding work. In order to understand clearly how it has been possible to achieve such remarkable success, it is necessary first to consider briefly some of the genetical phases of the breeding work, and to show how genetical research has simplified the problem.

Genetical Studies of Resistance

'Groups' of physiologic races.—The first essential to any plant-breeding programme is genetical variability, in the characters concerned, within the species or between completely or partially interfertile species. At least, this held until the method for artificially producing amphidiploids from completely sterile hybrids was developed. Genetical variability with respect to resistance to stem rust in *Triticum vulgare* was demonstrated in Australia by Farrer [3] about half a century ago. In

North America, however, only 20 years ago no variety of *T. vulgare* with more than very moderate resistance to *P. graminis tritici* under field conditions was known. The situation facing the plant-breeder was simply this: many physiologic races of *P. graminis tritici*, and more being identified year by year (over 150 are now known), and high resistance under field conditions found only in certain varieties of *Triticum durum* and *T. dicoccum*.

The first important simplification of the problem arose from results of genetical studies of seedling resistance to several physiologic races in the cross Marquis × Kanred made by Aamodt [4]. Of thirteen physiologic races used, Kanred seedlings were immune to eight. The results revealed that not only was the immunity to a single race inherited as a simple dominant, but that a single gene governed the inheritance of immunity to all of the eight races to which Kanred was immune. Thus any F_3-line inheriting from Kanred immunity to one of these races was likewise immune to the other seven. The importance of this discovery was immediately apparent. It meant that groups rather than individual races of *P. graminis tritici* constituted units from the plant-breeder's point of view. The larger the groups, the simpler the problem. Of course, such groups identified in one wheat cross do not necessarily hold good in another.

In studies by Goulden, Neatby, and Welsh [5], and by Neatby [6], in the cross H–44–24 × Marquis, it was revealed that the inheritance of seedling reactions to eighteen races was mainly controlled by two pairs of genes. The presence of minor modifiers was considered probable. This work culminated in the demonstration [7] that in the crosses Marquillo × Reward, Garnet × Marquillo, and Garnet × Double Cross, seedling reactions to a single race, determined in the greenhouse, would serve as a reasonably reliable measure of the resistance of adult plants in the field where many races were known to be present. The author concludes: 'The results obtained in all three crosses indicate that the inheritance of the field reaction to stem rust, as determined by percentage infection, *in these crosses* is mainly if not entirely controlled by the factors which govern the inheritance of the seedling reaction to form 21 in the greenhouse, as determined by pustule type.'

The variety Thatcher, developed at the University of Minnesota by Hayes and his associates [8], and now the leading variety in areas of the United States and Canada under hard red spring-wheat, constitutes a very practical example of the application of the genetic results just described. Its parentage is (Marquis × Iumillo) × (Marquis × Kanred). From Kanred, Thatcher inherits immunity to at least eleven physiologic races. From the durum variety Iumillo, it inherits resistance or immunity to another large group of races [9]. Under field conditions, although not so highly resistant to stem rust as some other new varieties, it maintains a high degree of resistance even when epidemics are severe. The field resistance of Thatcher is maintained despite its moderate susceptibility in the seedling stage to several races. It has not, however, been shown to develop a 'mature-plant' type of resistance inherited independently of seedling reactions.

'Mature-plant' resistance.—The identification of physiologic races of *P. graminis tritici* is based upon the reactions of seedlings. The tests are, of course, made in greenhouses: a practice necessitated by the impossibility of maintaining pure cultures of the organism under field conditions. However, since the common barberry is not found in the prairie provinces, and since wind-borne uredospores do not arrive until about the end of June, seedling reactions are of practical interest only in so far as they are related to the reactions of plants at or near the heading stage. Therefore, the discovery of a type of resistance which was not fully expressed until the heading stage, or later, which was apparently effective against all known physiologic races, and was inherited as a simple Mendelian dominant (in some crosses only), was revolutionary.

The variety H–44–24 was produced by McFadden [10] by crossing Yaroslav emmer (*T. dicoccum*) with Marquis. H–44–24 has remained practically immune to stem rust under field conditions in the prairie provinces and adjacent states. In 1927 Goulden, Neatby, and Welsh [11] published a summary of results of studies made with the cross H–44–24 × Marquis. The year following, a full account of the work appeared [5]. Field studies of 1054 F_3-families conducted under heavy epidemic conditions led to the conclusion that the high resistance to stem rust of H–44–24 was inherited as a simple dominant. The 1927 report constitutes the first published account of simple Mendelian inheritance of a high degree of resistance to stem rust of wheat under field conditions, though acknowledgement of this fact is conspicuously absent from most literature on the subject which has appeared since that time. Seedlings of the same F_3-families were inoculated, separately, with physiologic races 21 and 36 in the greenhouse. It was concluded that the 'mature-plant' resistance as observed in the field was inherited independently of the seedling reactions. After testing a group of F_3-lines to several physiologic races in the greenhouse, it was concluded that seedling reactions were worthless in selecting for the H–44–24 type of field resistance. The essential features of this work have been firmly established by the results of more recent investigations [12, 13, 14, 15, 16]. The most important conclusion to be drawn from these studies is that the mature-plant resistance of H–44–24 can be manipulated in wheat breeding as readily as any other simply inherited character provided, of course, that local conditions are suited to the development of heavy epidemics of stem rust. Accuracy of selection depends primarily upon satisfactory infection of susceptible types. The Red River Valley from Winnipeg, Manitoba, and southwards, is admirably suited to this purpose.

There are now three varieties in commercial production in Canada which possess the H–44–24 type of stem-rust resistance; they are Renown, Regent, and Apex. The two former varieties were selected from the cross H–44–24 × Reward at the Dominion Rust Research Laboratory, Winnipeg, and Apex was derived from the cross (H–44–24 × Double Cross) × Marquis. Double Cross is a strain originating from the cross from which Thatcher was selected. Apex, in addition to inheriting the high resistance of H–44–24, also inherits from Double Cross seedling-resistance to most of the physiologic races to which Thatcher is resistant [9].

Results of Comparative Field Tests

Experimental field data on the stem-rust reactions and yield of the four resistant varieties, together with Marquis for comparison, have been provided by Dr. R. F. Peterson of the Dominion Rust Research Laboratory, Winnipeg. The experimental design used for the tests from which the data in Tables 1, 2, 3, and 5 were derived was the 'balanced lattice'. The tests contained 25 varieties and 6 replications, and the plots consisted of 4 rod-rows each, 9 in. apart. The two outside rows of each plot were discarded at harvest.

TABLE 1. *Percentage Stem Rust on Five Wheat Varieties at the Dominion Rust Research Laboratory, Winnipeg, in the years 1935–41 inclusive*

Variety	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*1941*	*Mean*
Marquis . . .	77	73	75	80	38	78	55	68·0
Apex	8	3	1	2	1	3	3	3·0
Renown . . .	0	1	2	1	2	2	1	1·3
Regent . . .	0	1	1	1	2	2	1	1·1
Thatcher . . .	3	4	23	1	1	22	10	9·1

Marquis is manifestly susceptible. Apex, Renown, and Regent are almost immune, and there is no evidence whatever of progressive deterioration. The amount of rust on Thatcher varies a good deal from year to year, a characteristic observed by the author before the year 1935. Again, however, there is no evidence that Thatcher is less resistant under field conditions than it was ten or more years ago. It is peculiar that Apex should be slightly less resistant than Regent and Renown since, unquestionably, it carries the main H–44–24 factor for resistance and, in addition, one or more of the factors concerned in the resistance of Double Cross. The slightly higher rust-percentages on Apex are of no practical significance; it was bred and selected at Saskatoon, Saskatchewan, where natural epidemics are less frequent and less severe than at Winnipeg, and where it is considered unwise to induce artificial epidemics. Selection for minor factors for resistance, undoubtedly possessed by H–44–24 and inherited from it by Regent and Renown, would be difficult at Saskatoon. The significance of these data can readily be appreciated by referring to investigations on the relation between percentage infection and yield conducted by Goulden and Greaney [17]. Graded infections were obtained by varying the amount and frequency of sulphur-dust applications in plots of Marquis wheat. The plots were arranged in the form of a 14×14 Latin square. Two other experiments involved 7×7 and 8×8 Latin squares. Yield—rust-percentage relations were established by means of regression equations. In one experiment (14×14), each 10 per cent. increase of rust reduced the yield by 6·8 per cent. In the others (7×7 and 8×8), yield was reduced 9·7 per cent. for each 10 per cent. increase in rust.

In the Winnipeg tests reliance is not placed on natural epidemics. Instead, composites of uredospores containing thirty or more physiologic races are propagated on susceptible varieties grown along the ends of all

plots. Only when conditions are very unfavourable does this method fail to produce heavy infections on susceptible varieties.

TABLE 2. *Yield (bushels per acre) of Five Wheat Varieties at the Dominion Rust Research Laboratory, Winnipeg, in the years 1935–41 inclusive*

Variety	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*1941*	*Mean*
Marquis . . .	1·9	9·5	5·1	5·0	25·6	12·7	20·7	11·5
Apex	12·3	10·4	28·1	17·6	31·0	34·0	26·0	22·8
Renown . . .	21·2	8·7	32·3	23·9	32·0	42·4	33·8	27·8
Regent . . .	21·1	7·9	37·0	25·7	30·2	46·0	35·0	29·0
Thatcher . . .	21·8	15·3	34·4	18·1	27·6	44·9	25·7	26·8

TABLE 3. *Yield (bushels per acre) of Five Wheat Varieties at the Dominion Experimental Farm, Brandon, Manitoba, in the years 1935–41 inclusive*

Variety	*1935*	*1936*	*1937*	*1938*	*1939*	*1940*	*1941*	*Mean*
Marquis . . .	8·8	25·4	24·2	15·6	28·7	32·5	37·8	24·7
Apex	30·2	23·1	30·6	44·6	34·9	37·9	38·8	34·3
Renown . . .	37·8	23·1	28·5	50·7	43·1	37·8	45·6	38·1
Regent . . .	40·3	24·4	32·0	48·9	46·4	38·1	43·7	39·1
Thatcher . . .	43·5	30·1	37·8	45·7	47·8	39·1	46·0	41·4

The effect of stem rust on the yield of Marquis is apparent in Table 2. In two years only did Marquis yield in excess of 20 bushels per acre, and in these two years, namely 1939 and 1941, the rust infection was comparatively light. The low yields of varieties in 1936 are attributed by Dr. Peterson to severe drought conditions.

The tests at Brandon (Table 3) were conducted under conditions of natural infection. The severe losses from stem rust suffered in southern Manitoba and Saskatchewan in 1935 and 1938 are reflected, as would be expected, by the low yields of Marquis at Brandon in those years. The differences between the yields of Marquis and the other varieties serve as an indication of the tremendous losses suffered prior to the distribution of resistant varieties. For further information on the subject of losses, the reader is referred to papers by C. H. Goulden and F. J. Greaney [17] and F. J. Greaney [18].

Additional sources of breeding material.—The variety Iumillo (*T. durum*) has proved virtually immune at every stage of development to all physiological races with which it has been inoculated. So far, attempts to transfer this immunity intact to *T. vulgare* have failed. According to Peterson and Love [19], 'The aim of developing varieties of *Triticum vulgare* having the immunity to stem rust of Iumillo has been closely approximated though not fully achieved'.

Peterson, Johnson, and Newton [20] report that five varieties of *T. vulgare* obtained from Kenya, and one selected by a farmer in Manitoba, are 'practically immune at all stages of growth to all physiologic races of stem rust occurring in Canada'. Dr. Peterson informs me that the resistance of the wheat originating in Manitoba, and one of the Kenya wheats, has a similar genetical basis; namely, one main recessive gene for

resistance plus minor modifiers which may differ from one variety to another. Moreover, since this main gene is not allelomorphic to the one chiefly concerned in the resistance of H–44–24, the Kenya variety and the Manitoba strain, known as McMurachy's Selection, constitute new sources of resistance. Johnson and Newton [21] have shown that, although the Kenya and McMurachy wheats are highly resistant to stem rust under field conditions in Manitoba, they become susceptible when grown in the greenhouse under high temperatures. The same authors have shown that certain other wheats, including varieties of *T. vulgare*, are immune or highly resistant, regardless of whether they are grown under low, moderate, or high temperatures. The most important aspect of these discoveries concerns the assurance that *even if* Thatcher, and the other three varieties which inherit resistance from H–44–24, should succumb to new physiologic races of *P. graminis tritici*, yet we still have other sources of resistance with different genetical bases available.

Distribution of Varieties resistant to Stem Rust in the Prairie Provinces

One of the most serious stem-rust epidemics in the history of Canadian wheat production occurred in 1935. Since that time the varietal constitution of the prairie-province wheat crop has undergone a change which is almost complete. Through the assistance of some 2,500 country elevator agents, the Agricultural Department of The North-West Line Elevators Association has estimated the acreage occupied by different wheat varieties in 1941. In Table 4 the results of this survey are recorded, together with data obtained in 1936, by the Research Department of the Searle Grain Company.[1]

TABLE 4. *Percentages of Total Wheat Acreage in the Prairie Provinces occupied by Different Varieties of Wheat in 1936 and 1941*

Variety	*Manitoba*		*Saskatchewan*		*Alberta*[2]		*All provinces*	
	1936	*1941*	*1936*	*1941*	*1936*	*1941*	*1936*	*1941*
Thatcher	..	61·8	..	63·8	..	6·6	..	45·5
Renown	..	22·2	..	4·1	..	1·3	..	4·9
Regent	..	7·7	..	3·0	..	0·2	..	2·5
Apex	..	1·0	..	8·3	..	0·2	..	5·0
Marquis	22·1	0·1	72·6	17·0	49·2	36·7	59·4	21·7
Red Bobs	0·5	0·1	0·5	1·4	18·9	47·3	6·4	15·8
Ceres	24·0	..	3·3	..	0·1	..	4·6	..
Garnet	2·0	0·0	8·5	0·1	22·4	2·5	12·3	0·9
Reward	10·8	0·5	9·0	0·7	6·8	1·4	8·5	0·9
Reliance	..	0·2	..	0·1	..	0·1	..	0·1
Canus	..	0·0	..	0·0	..	2·3	..	0·8
T. durum	38·9	6·1	4·2	0·9	0·1	0·0	6·7	1·1
Winter wheat	..	0·0	..	0·0	..	0·9	..	0·3
Miscellaneous	1·7	0·3	1·9	0·6	2·5	0·5	2·1	0·5

The four varieties Thatcher, Apex, Renown, and Regent occupied 91·7 per cent. of the Manitoba wheat acreage in 1941, and 79·2 per cent. of

[1] By permission of Major H. G. L. Strange, Director, Research Department, Searle Grain Company, Limited.

[2] Including British Columbia section of Peace River district.

the Saskatchewan acreage. In other words, susceptible varieties have practically disappeared from the 'rust area' since 1936. The so-called rust area may be said to occupy the central and southern part of the

TABLE 5. *Average Yield (bushels per acre) of Five Wheat Varieties in Co-operative Tests in the Prairie Provinces in the years 1934–41 inclusive*

Variety	*Manitoba*	*Saskatchewan*	*Alberta*
Marquis . .	21·5	20·7	32·0
Apex . . .	28·2	21·7	31·1
Renown . . .	31·0	20·9	29·9
Regent . . .	33·8	22·1	32·0
Thatcher . .	33·7	24·7	35·1

farming area of Manitoba, and southern and east central Saskatchewan. Proceeding north and west from this area, epidemics become less frequent and, usually, less destructive. In the northerly and western parts of Alberta, damage is rare. It is for this reason that the new rust-resistant varieties have made comparatively little progress in the province of Alberta. The relatively minor importance of stem rust in Alberta and, in general, in Saskatchewan, is illustrated by the data in Table 5. The number of stations at which tests were made each year varied from three to six in Alberta, from three to seven in Saskatchewan, and from five to six in Manitoba. These tests were widely distributed, and so give a general picture of rust losses. At Winnipeg and Brandon (Tables 2 and 3) average annual losses are much greater than over Manitoba as a whole. Likewise, in Saskatchewan losses are often severe in the south-east, though over the province as a whole, for the period 1934 to 1941, Marquis yielded comparatively well.

Conclusion.—Notwithstanding minor defects in new rust-resistant varieties, the mastery of the stem-rust problem is an achievement of the first order. It has resulted from the combined efforts of plant-breeders, plant-pathologists, agronomists, and cereal chemists. Apart from the economic benefits which have resulted, contributions to existing knowledge of the biology of *Puccinia* spp., of the genetics of rust-resistance, and of factors affecting 'wheat quality' and its measurement, have been substantial.

Acknowledgements.—I am indebted to Dr. C. H. Goulden, who has directed the breeding and genetical investigations at the Dominion Rust Research Laboratory since 1925, when the work was begun; and to Dr. R. F. Peterson, of the same institution, for criticism of the manuscript.

REFERENCES

1. E. C. STAKMAN and M. N. LEVINE, The Determination of Biologic forms of *Puccinia graminis* on *Triticum* spp. Minn. Agric. Expt. Stat., 1922, Tech. Bull. No. 8.
2. —— ——, and F. J. PIEMEISEL, Biologic forms of *Puccinia graminis* on Cereals and Grasses. J. Agric. Res., 1917; **10**, 429–95.
3. W. FARRER, The Making and Improvement of Wheats for Australian Conditions. Agric. Gaz. N.S.W., 1898, **9**, 131–68.

4. O. S. AAMODT, The Inheritance of Growth Habit and Resistance to Stem Rust in a Cross between two Varieties of Common Wheat. J. Agric. Res., 1923, **24,** 457–70.
5. C. H. GOULDEN, K. W. NEATBY, and J. N. WELSH, The Inheritance of Resistance to *Puccinia graminis tritici* in a Cross between two Varieties of *Triticum vulgare*. Phytopath., 1928, **18,** 631–58.
6. K. W. NEATBY, Factor Relations in Wheat for Resistance to Groups of Physiologic Forms of *Puccinia graminis tritici*. Sci. Agric., 1931, **12,** 130–54.
7. ——, The Type of Infection of Wheat Seedlings by *Puccinia graminis tritici* in the Greenhouse as a Measure of the Percentage Infection in the Field. Sci. Agric., 1933, **13,** 625–35.
8. H. K. HAYES, E. R. AUSEMUS, E. C. STAKMAN, C. H. BAILEY, H. K. WILSON, R. H. BAMBERG, M. C. MARKLEY, R. F. CRIM, and M. N. LEVINE, Thatcher Wheat. Univ. of Minn., 1936, Bull. No. 325.
9. MARGARET NEWTON, T. JOHNSON, and B. PETURSON, Seedling Reactions of Wheat Varieties to Stem Rust and Leaf Rust and of Oat Varieties to Stem Rust and Crown Rust. Canad. J. Res., 1940, C, **18,** 489–506.
10. E. S. MCFADDEN, 'Synthetic' Rust-proof Bread Wheats. Dakota Farmer, 1925, **45,** 102.
11. C. H. GOULDEN, K. W. NEATBY, and J. N. WELSH, The Inheritance of Resistance to *Puccinia graminis tritici* in a Cross between two Varieties of *Triticum vulgare*. Anatomical Record, 1927, **37,** 182 (Abst.)
12. E. R. AUSEMUS, Correlated Inheritance of Reaction to Diseases and of Certain Botanical Characters in Triangular Wheat Crosses. J. Agric. Res., 1934, **42,** 31–7.
13. J. ALLEN CLARK and H. B. HUMPHREY, Inheritance of Stem-rust Reaction in Wheat. J. Amer. Soc. Agron., 1933, **25,** 497–511.
14. —— ——, and GLENN S. SMITH, Inheritance of Stem-rust Reaction in Wheat. II. Ibid., 1935, **27,** 400–7.
15. C. H. GOULDEN and K. W. NEATBY. Breeding Rust-resistant Varieties of Spring Wheat. Ibid., 1931, **23,** 859–870.
16. K. W. NEATBY and C. H. GOULDEN, II. The Inheritance of Resistance to *Puccinia graminis tritici* in Crosses between Varieties of *Triticum vulgare*. Sci. Agric., 1930, **10,** 389–404.
17. C. H. GOULDEN and F. J. GREANEY, The Relation between Stem-rust Infection and the Yield of Wheat. Ibid., 1930, **10,** 405–10.
18. F. J. GREANEY, Cereal Rust Losses in Western Canada. Ibid., 1936, **16,** 608–14.
19. R. F. PETERSON and R. M. LOVE, A Study of the Transference of Immunity to Stem Rust from *Triticum durum* var. Iumillo to *T. vulgare* by Hybridization. Ibid., 1940, **20,** 606–23.
20. ——, T. JOHNSON, and MARGARET NEWTON, Varieties of *Triticum vulgare* practically Immune in all Stages of Growth to Stem Rust. Science, 1940, **91,** 313.
21. T. JOHNSON and MARGARET NEWTON, The Effect of High Temperature on the Stem-rust Resistance of Wheat Varieties. Canad. J. Res., 1941, C, **19,** 438–45.

(Received June 23, 1942)